AN EVALUATION OF THE COST EFFECTIVENESS OF AGRICULTURAL BEST MANAGEMENT PRACTICES AND PUBLICLY OWNED TREATMENT WORKS IN CONTROLLING PHOSPHORUS POLLUTION IN THE GREAT LAKES BASIN

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DISCLAIMER

CONTENTS

CONTENTS (cont'd)

EXECUTIVE SUMMARY

Nonpoint source water quality problems have been identified as the principal remaining cause of water quality problems in six of ten U.S. Environmental Protection Agency (EPA) regions (EPA, 1984). Consequently progress in water cleanup will require effective control of nonpoint source pollution, especially from agricultural lands.

The primary purpose of this study was to analyze the cost-effectiveness of various pollution control strategies in the Great Lakes Basin. The first step in this effort was a literature review of agricultural best management practices (BMPs), with emphasis on studies in EPA Region V; critical factors influencing the cost-effectiveness of BMPs in controlling sediment and phosphorus were identified. Then a case study was undertaken to estimate the costs and effectiveness of conservation tillage in reducing phosphorus loads in the Honey Creek watershed in Ohio. The third step in the analysis was to identify publicly owned treatment works (POTWs) in Region V which have recently been built or upgraded beyond secondary treatment for phosphorus control and estimate the associated costs. Finally a cost-effectiveness comparison was completed for the POTWs and conservation tillage based on the case study.

A. Review and Analysis of Literature

Practices which reduce soil, and nutrient losses from agricultural lands have been studied for a considerable length of time. Many of these studies have focused on the potential of diminished agricultural productivity resulting from soil and nutrient losses. However; more recent studies have centered on agricultural runoff and its contribution to water pollution. Because of variations in critical site specific conditions -- for example changes in field slope, soil texture, crop and rainfall patterns for field related BMPS -- there is considerable variation in the cost-effectiveness of each BMP. Table 1 presents a summary of findings (as expressed in the literature) regarding some of the most commonly used BMPs for which quantitative cost and effectiveness data are available.

B. Conservation Tillage Case Study

Conservation tillage is a cultural practice which can effectively reduce the quantity of nonpoint phosphorus loadings. However, because of the variable nature of storm events which trigger nonpoint loads, the implementation of a BMP such as conservation tillage may not reduce these loads to acceptable (targeted) levels in a given year. Potentially greater use of pesticides with conservation tillage also raises concerns about environmental damage resulting from its widespread implementation. Consequently, phosphorus and pesticide loading functions for surface and ground water contamination were estimated for alternative land use practices, crop production practices and historical weather patterns. Net returns were also estimated for various crops, tillage systems and land classifications. The cost-effectiveness of conservation tillage in reducing phosphorus loads was then estimated by a linear programing (LP) model, with and without pesticide use constraints.

The cost-effectiveness estimates for the Honey Creek watershed are based on critical assumptions regarding baseline cropping and tillage practices. The prevailing dropping and tillage practices during the period when the Honey Creek land use surveys were conducted (1979-1982) are defined as the baseline. Under this definition, approximately 25 percent of the row crop acreage is in continuous corn, 15 percent is in continuous soybeans and the remaining 60 percent is in a corn and soybean rotation. All acreage is managed with conventional tillage practices. Total. edge-of-stream phosphorus loadings from the 58,358 acres of crops in the watershed are estimated to be 113,565 pounds under baseline cropping and tillage practices.

Table 1. Estimated cost and effectiveness ranges of major Best Management Practices (BMPs) used in the Great lakes Basin for agriculture production 1/

	Costs			Yield change	Soil loss	Phosphorus loss	Cost-effectiveness in edge-of-field reduction of	
	Investment	O&M	Annualized 2/				Soil 3/	Phosphorus 4/
	--------------dollars per acre--------------			percent	--percent reduction--		dollars/ton per year 5/	dollars/pounds per year 5/
Conservation Tillage								
Low till	---	-3 to -7.50	-3 to -7.50	±10	30-60	25-50	<0 to 27.50	<0 to 198
No-till	---	-5 to -15	-5 to -15	±10	60-90	50-80	<0 to 11.10	<0 to 80
Contouring	3 to 12	3 to 6	3.50 to 8.00	-	40-80	35-75	.36 to 4.79	0.77 to 32.86
Terraces	61.25 to 720	3 to 36	10.20 to 120.60	-	50-90	50-75	3.63 to 43.60	8.72 to 261.60
Grassed Waterways 6/	16 to 40	0.80 to 2.00	2.70 to 6.70	-	60-80	40-50	0.29 to 2.61	0.94 to 23.50
Sediment Basins 7/	100 to 300	10 to 30	26.30 to 78.80	-	60-95	25-50	2.77 to 29.20	10.50 to 420
					Solids loss	**Phosphorus loss**	**Cost-Effectiveness in edge-of-feedlot reduction of**	
	------------dollars per feedlot------------						**Solids**	**Phosphorus 9/**
Feedlot Runoff Control								
100 head feedlot	5,000 to 12,000	300 to 600	890 to 2,010	-	80-90	70-95	8/	3.05 to 13.80
500 head feedlot	9,000 to 16,000	400 to 800	1,460 to 2,680	-	80-90	70-95	8/	0.90 to 3.95
1,000 head feedlot	11,000 to 20,000	500 to 1,000	1,790 to 3,350	-	80-90	70-95	8/	0.55 to 2.45

1/ Cost and effectiveness estimates based on review of the literature as presented in Chapter II and Appendix A.

2/ Investment costs are annualized at a 10 percent rate over the useful life of the BMP.

3/ Sediment losses before implementation of each BMP are estimated to range from 3 to 20 tons per acre.

4/ Phosphorus losses before implementation of each BMP are estimated to range from 0.5 to 10 pounds per acre.

5/ Cost-effectiveness estimates are calculated using the midpoint of the annualized cost range estimate for each BMP.

6/ Grassed waterway costs are estimated on the assumption that one acre of grassed waterway will serve 75 acres of cropland.

7/ Sediment basin costs are estimated on the assumption that each basin serves 8 acres of cropland.

8/ Sufficient information regarding baseline solids losses were not available to derive cost-effectiveness estimates.

9/ Phosphorus losses without controls are estimated to range from 1.5 to 5.0 pounds per ton per year.

The cost-effectiveness of conservation tillage in reducing phosphorus loads is dependent on both. the targeted load reduction and the desired reliability of actually achieving these reductions in any given year. Targeted watershed reductions of 10, 25, 50 and 75 percent for phosphorus loadings and reliability thresholds.for achieving these reductions in any given year of 50, 60, 75 and 95 percent were estimated and are presented below.

Reliability 1/ (percent)	Targeted reduction in phosphorus pollution (percent of baseline load) 10	25	50	75
	1985 $/pound			
50	2/	0.71	5.10	13.20
60	2/	2.57	6.44	18.11
75	5.23	6.75	9.11	34.04
95	25.54	15.06	20.12	3/

1/ Reliability of meeting or exceeding the targeted reduction in any given year.

2/ Cost-effectiveness measure is negative, reflecting more profitable tillage practices and cropping patterns than defined by baseline conditions.

3/ Infeasible solution.

Because of concerns about potential increases in use and environmental damage from pesticides, pesticides use restrictions were imposed based on estimated pesticide loading functions. With pesticide use restrictions sufficient to meet Recommended Maximum Contamination Levels (RMCLs) in drinking water, costs for reducing phosphorus loadings increase -- in some cases dramatically. Cost-effectiveness estimates for phosphorus load reductions are presented below. In this analysis, targeted phosphorus load reductions and RMCLs are both expected to be met with 50 percent reliability.

Targeted phosphorus reduction percent of baseline)	Reliability of achieving phosphorus reduction (percent)	Reliability of achieving pesticide RMCLs (percent)	Cost ($/pound)
10	50	50	1.83
25	50	50	4.09
50	50	50	7.17
75	50	50	16.10

Higher levels of reliability for meeting the targeted phosphorus load reductions and RMCLs were also estimated. The results of this analysis indicated significantly higher costs per pound of phosphorus load reductions.

C. Cost-effectiveness of POTWs Controlling Phosphorus

POTWs with planned or upgraded facilities for phosphorus removal were identified in EPA Region V. Facilities were identified by consulting two data sources, the EPA Needs Survey (EPA, 1985a), which identified 208 POTWs being upgraded for phosphorus removal, and Region V's "Construction Grants Information and Central System for Advanced Treatment Projects," which identified 26 POTWs being upgraded for phosphorus removal (EPA, 1985). A sample of POTWs listed in the Needs Survey was contacted to determine plans to build or upgrade for phosphorus removal. Only a small number of these POTWs contacted indicated they were upgrading specifically for phosphorus removal. Accordingly, because of resource constraints, the cost-effectiveness analysis was focused on the 26 POTWs identified by EPA Region V as being upgraded specifically for phosphorus removal.

These facilities were contacted in order to obtain data sufficient to complete a cost-effectiveness analysis. Data required for this analysis consisted of the following:

- POTW size in million gallons per day (MGD);
- number of operating days or annual flow;
- influent and effluent phosphorus concentrations;

- advanced treatment technology used; and
- capital and annual operation and maintenance costs for phosphorus removal.

These data were collected through telephone interviews with the POTW operators or engineers. The contacts were asked to estimate costs for removal of phosphorus only. This was an especially troublesome task insofar as capital costs are aggregate figures associated with the total facility construction or upgrade, and are not broken out by the specific pollutant (e.g., phosphorus) treated. All estimates received were verified via follow-up contacts with the POTWs.

Of the 26 POTWs identified by EPA Region V as being upgraded for phosphorus removal, six were deleted after initial contacts because they were not upgrading specifically for phosphorus removal. Additionally, nine POTWs could not provide adequate information to conduct the cost-effectiveness analysis. Consequently only eleven POTWs were considered in the final cost-effectiveness analysis, with only average costs being estimated.

Chemical addition to precipitate phosphorus was the most common treatment used by the eleven POTWs. All but one facility used this treatment process. The chemicals used included aluminum sulfate, ferric chloride, iron and polymers and steel mill waste pickle liquor. Pickle liquor was a cheaper substitute for chemicals. The Rochester, Minnesota POTW was the one facility using a proprietary treatment process called PhoStrip. This process is both a biological and chemical treatment process.

The POTWs ranged in size from 0.3 to 10 million gallons per day (MGD) with capital costs for removal of phosphorus ranging from $20,000 to $3,500,000 while annual operation and maintenance costs ranged from $2,500 to $450,000.

Of the eleven POTWs analyzed, influent ranged from 2.0 milligrams per liter (mg/l) to 14.0 mg/l while effluent ranged from 0.1 mg/l to 1.0 mg/l. Total phosphorus removed ranged from 1,461 pounds to 395,292 pounds. Cost-effectiveness estimates ranged from $1.14 per pound to $20.58 per pound of phosphorus removed with higher costs being associated with smaller facilities.

Since similar treatment systems are used, the POTWs were grouped by size to develop average cost-effectiveness values. Values for three sizes of facilities are presented below.

Size Range (MGD)	Average Size (MGD)	Cost-effectiveness Range (1985 $/lb)	Cost-effectiveness Weighted Average (1985 $/lb)
< 0.5	0.4	6.06 - 20.58	9.55
0.5 - 1.9	1.2	1.22 - 14.39	3.77
2.0 & up	5.8	1.14 - 2.18	2.00

In a similar study of POTWs in the Great Lakes basin, significant economies of scale were experienced by larger facilities (SAIC, 1988). The results of this study are summarized below.

Size Range (MGD)	Average Size (MGD)	Cost-effectiveness Range (1985 $/lb)	Cost-effectiveness Weighted Average (1985 $/lb)
< 5.0	3.2	0.98 - 2.06.	1.37
5.0 - 9.9	7.7	0.54 - 2.47	1.24
10.0 - 19.9	13.4	0.45 - 1.22	0.68
20.0 & up	52.7	0.23 - 0.92	0.41

The analyses did not estimate the impact on costs and cost-effectiveness stemming from incremental increases in the levels of treatment of POTWs, but rather reported the average costs and cost-effectiveness for upgrading from secondary treatment to current levels of phosphorus control (which include phosphorus effluents equivalent to advanced secondary and advanced levels of treatment).

D. Comparison of Conservation Tillage and POTW Cost-effectiveness Estimates

A comparison of the cost-effectiveness of conservation tillage versus POTWs in reducing nonpoint phosphorus loadings requires the consideration of several factors. Of critical importance in assessing the cost-effectiveness of conservation tillage is the desired level of reduction in phosphorus loadings to be achieved and the acceptable reliability (probability) of meeting the desired levels in any given year. Of critical importance in assessing the cost-effectiveness of POTWs is the size of the facility for the watershed in question.

The higher the watersheds targeted reduction in phosphorus loads, the higher the average cost per pound of phosphorus load reductions with conservation tillage. In the Honey Creek watershed, POTWs decreasing phosphorus levels to one milligram per liter or less are cost-effective (compared to conservation tillage) if targeted reductions for the watershed are greater than 75 percent, regardless of the size of POTW needed. At targeted reductions of 50 percent, POTWs with capacities greater than 500,000 gallons per day are cost-effective.

At targeted reduction levels of 25 percent, the cost-effective phosphorus control method depends on the desired reliability of achieving the targeted reduction levels in any given year. If meeting the long-run targets is sufficient (i.e., 50 percent reliability assuming the phosphorus pollution probability distribution is normally distributed), conservation tillage is cost-effective compared to POTWs treating less than 10 MGD. If a higher degree of reliability is deemed necessary (i.e., >60 percent), POTWs designed to treat more than 2 MGD are cost-effective.

I. INTRODUCTION

Since the passage of the Clean Water Act in 1972, significant progress toward achievement of the nation's water quality objectives has been accomplished by controlling point sources of pollution. These reductions have resulted from the development and installation of point source technologies, regulatory activities and effective enforcement actions.

Unfortunately, the overall quality of the nation's surface waters has not improved to an extent proportional with the point source reductions. It is becoming increasingly recognized that continued improvement in the quality of the nation's waterways will also require significant reduction in pollutants from nonpoint sources. As highlighted in a recent U.S. Environmental Protection Agency (EPA) publication Report to Congress: Nonpoint Source Pollution in the U.S., nonpoint source pollution is indeed a pervasive problem. Nonpoint sources have been identified as the principal remaining cause of water quality problems in six of ten EPA Regions (EPA, 1984).

Nonpoint sources contribute both conventional and toxic pollutants as do point sources. Even though both sources contribute the same kind of pollutants, the process of pollutant generation is very different in that pollutants from nonpoint sources are mobilized primarily during storm events. In addition, generation rates vary from site to site in volume, combinations and concentrations during different flow regimes. Therefore, pollution from nonpoint sources occurs with less frequency and for shorter duration than for point sources (EPA, 1984).

Agriculture has been identified as the most pervasive source of nonpoint water quality problems in most areas of the United States, Sediment (such as sand, silt, clay and organic materials) as eroded soil carried in runoff is the largest contribution by volume to nonpoint source pollution (EPA, 1984). Because of the high volume, sediment can result in serious problems by upsetting stream and lake ecosystems, settling out of the water column and destroying benthic habitats, and causing high turbidity which inhibits photosynthesis. It also has a significant adverse effect on fish reproduction and feeding. Sedimentation decreases storage capacity in lakes and reservoirs, increases flooding, reduces the effectiveness of drainage ditches and increases water treatment costs (Clark et al., 1985).

Nutrients--in particular, phosphorus and nitrogen--are the most significant contaminants in eroded soil and runoff (Clark et al., 1985). Eutrophication, caused by excessive nutrients results in fish kills, nuisance algal blooms, heavy aquatic weed growth, poor taste and foul odors. Nitrogen contamination of drinking water supplies can also cause nitrate poisoning (Johnson et al., 1982). Nutrient export from agricultural lands is influenced by the same factors that influence the erosion process itself as well as several others. Particularly important are farm-management practices, cropping patterns, soil type, topography, fertilizer management, livestook and livestock waste management, and weather.

Numerous other contaminants are associated with agricultural nonpoint pollution. Pesticides, like nutrients, are transported from agricultural lands by being adsorbed to eroding soil particles, dissolved in runoff water and leached into groundwater. Other agricultural nonpoint source contaminants include bacteria, viruses, metals and salts.

Control of agricultural nonpoint source pollution is a complex problem. Variable conditions among sites make the problem of control very site specific. As a result; generalized solutions at the national level are elusive. Progress has been made in understanding the causes of agricultural nonpoint pollutants and actual progress in controlling nonpoint source pollution, in some instances, has been significant.

Although understanding of nonpoint source pollutants resulting from agricultural activities is increasing, the broad pervasive trends in agriculture have increased the problem in recent years. Conversion of marginal land to cropland, increased intensive agriculture, and double cropping have resulted in an overall increase in agricultural nonpoint pollution.

Several management practices can be implemented to control agricultural nonpoint pollution. Previous research has shown that it may be more cost-effective--at least in certain circumstances--to manage nonpoint sources of pollution rather than upgrading publicly owned treatment works (POTWs) (IEc, 1985). Identification and a clearer understanding of the cost-effectiveness of various types of pollution control will help to ensure the adoption of efficient and effective management programs. This can help to achieve desired levels of water quality protection in the context of competing resources.

A. Purpose and Background of Study

The primary purpose of this study was to evaluate the economic tradeoffs between implementing agricultural best management practices (BMPs) and stricter point source controls for reducing phosphorus loadings in the Great Lakes area--primarily EPA Region V. The first step in this effort was a literature-review of agricultural BMPs. The primary purpose of this review was to assess the cost-effectiveness of each BMP in reducing phosphorus in agricultural nonpoint source runoff. Ancillary research involved an assessment of water runoff and soil loss resulting from implementing the various BMPs; this information was deemed important in developing a clearer understanding of the effectiveness of the BMPs in reducing phosphorus losses. Site-specific criteria which are critical in the cost-effectiveness of the BMPs were documented.

The second step in the analysis was to identify POTWs in Region V which have recently been built or upgraded beyond secondary treatment. Additional costs for nutrient removal were assessed and cost-effectiveness estimates were developed for different sizes of POTWs. The final task in the original scope of work was to compare the BMP cost-effectiveness with that of POTWs in reducing phosphorus loadings in the Great Lakes Basin. However, most of the cost-effectiveness information available on BMPs was on an edge-of-field basis, and accordingly was not directly comparable with the POTW estimates. In light of this and other problems (e.g., concern about the reliability of BMPs in meeting water quality objectives in a. given year due to the variability in storm and runoff events which trigger much or the nonpoint pollution) the scope of work was altered to include a case study of the cost-effectiveness of conservation tillage in reducing nonpoint phosphorus loadings in the Honey Creek watershed in Ohio.

Conservation tillage is a BMP which reduces soil erosion and phosphorus losses through a reduction in tillage operations and an increase in crop residues on the soil surface. The perception of increased use of pesticides with conservation tillage is considered to be a negative aspect of this BMP and has raised concern about increased pesticide loadings. In an effort to assess the overall desirability of implementing conservation tillage practices to reduce phosphorus loadings to surface water, pesticide use constraints were considered. These constraints were imposed to evaluate the physical and economic effects of conservation tillage on pesticide loadings to surface and ground water.

The case study relied on the use of a simulation program to estimate the sediment and phosphorus runoff effects of conservation tillage under the soil and climatic conditions of the Honey Creek watershed. Edge-of-stream phosphorus loadings were estimated by EPA analysts. Recognizing that the magnitude of phosphorus loadings occurring in a given year are dependent on the year's weather pattern, phosphorus loadings were estimated under average conditions as well as more extreme conditions when loadings would naturally be higher. This was done to provide a means of ensuring that targeted reductions in phosphorus loadings could be met with a high probability--as they are with point source controls. For example, targeted annual reductions in phosphorus loadings based on average loadings will only be met with 50 percent frequency (if phosphorus loadings are normally distributed). By targeting phosphorus load reductions based on more extreme weather conditions (e.g., higher expected loadings), the probability of actually meeting the targeted reduction in any time period will be increased.

These phosphorus loading estimates were used as constraints in a linear programing (LP) simulation model. The objective function of the LP model was to maximize farm income and was based on crop yield and farm income data (i.e., crop enterprise budgets) for conservation tillage practices. Effects of pesticide use constraints were incorporated into the model by altering objective function parameters to reflect the cost and yield estimates stemming from use of the various pesticides. The cost-effectiveness of conservation tillage was estimated by dividing the change in watershed farm income by the corresponding targeted reduction in phosphorus loadings.

The final step in the, study was a cost-effectiveness comparison between conservation tillage and POTWs in reducing phosphorus loadings. For purposes of this analysis, the total changes in farm income were attributable to reductions in phosphorus; none of the reductions in farm income were attributed to other benefits of conservation tillage (e.g., reductions in soil erosion and other nutrients).

B. Organization of Report

In Chapter II, cost-effectiveness ranges are presented for conservation tillage, contouring, terraces, grassed waterways, fertilizer management, sediment basins, livestock exclusions and feedlot runoff waste management. These estimates are based on the analysis of the literature presented in Appendix A pertaining primarily to the Great Lakes states. Important site-specific factors which affected the cost-effectiveness of each BMP are highlighted.

The case study of the cost-effectiveness of conservation tillage in reducing nonpoint phosphorus loadings is presented in Chapter III. A description of the Honey Creek watershed and a brief discussion. of the data used in this analysis is presented. Cost-effectiveness estimates are presented for targeted reductions of 10, 25, 50 and 75 percent in phosphorus loadings from the watershed, with varying levels of reliability for achieving the targeted reductions.

Cost-effectiveness estimates for POTWs in reducing phosphorus loadings are presented in Chapter IV; The POTWs examined are primarily located in EPA Region V and are facilities which were built or upgraded to go beyond secondary treatment. A brief comparison of the BMP and POTW cost-effectiveness estimates is presented in Chapter V.

II. COST-EFFECTIVENESS RANGE ESTIMATES FOR AGRICULTURAL BMPS

Managing agricultural nonpoint sources of pollution presents a series of complex control problems. The localized nature of crop production conditions, for example, makes adoption of a given BMP over a wide area impractical in most cases. Slight changes in field conditions, as indicated by a review of the literature, can have substantial effects on both the cost of implementation and relative effectiveness of various agricultural BMPs.

The cost-effectiveness range estimates presented in this chapter are primarily based on the review of the literature (as presented in Appendix A). Cost estimates are comprised of investment costs, annualized over the expected life of the BMP, annual (operation and maintenance) costs and any other changes in farm income resulting from changes in yields, cropped acreage, etc. 1/ Effectiveness range estimates, also based on published literature, are given for reductions in both phosphorus and soil losses. For purposes of the cost-effectiveness analysis of conservation tillage, contouring, terracing, grassed waterways, and sediment basins, it is assumed that soil loss under typical conditions, before implementation of any BMP, is in the range of 3 to 20 tons per acre per year, and phosphorus loss ranges from 0.5 to 10 pounds per acre.per year. Of course, soil and phosphorus losses will deviate from these ranges in some instances; however, based on a review of the literature, these ranges appear typical. Appropriate reductions are then estimated for each conservation practice based on results published in the literature. Factors critical to the cost-effectiveness of each BMP are briefly discussed. The overall results are presented in Table II-1 and discussed by management practice below.

1/ Investment costs are annualized using a capital recovery factory based on a cost of capital of 10 percent and the life of the investment. For purposes of this analysis, tax consequences including investment tax credit, depreciation, etc. are ignored. All cost estimates presented in this chapter are based on 1985 dollars.

Table II-1. Estimated cost and effectiveness ranges of major Best Management Practices (BMPs) used in the Great lakes Basin for agriculture production (per acre) 1/

	Costs 2/			Yield change	Soil loss	Phosphorous loss	Cost-effectiveness in edge-of-field reduction of 2/	
	Investment	O&M	Annualized				Sediment 3/	Phosphorus 4/
	--------------dollars per acre------------			percent	--percent reduction--		dollars/ ton 5/	dollars/ pound 5/
Conservation Tillage								
Low till	NA	-3 to -7.50	-3 to -7.50	±10	30-60	25-50	<0 to 27.50	<0 to 198
No-till	NA	-5 to -15	-5 to -15	±10	60-90	50-80	<0 to 11.10	<0 to 80
Contouring	3 to 12	3 to 6	3.50 to 8.00	-	40-80	35-75	.36 to 4.79	0.77 to 32.86
Terraces	61.25 to 720	3 to 36	10.20 to 120.60	-	50-90	50-75	3.63 to 43.60	8.72 to 261.60
Grassed Waterways 6/	16 to 40	0.80 to 2.00	2.70 to 6.70	-	60-80	40-50	0.29 to 2.61	0.94 to 23.50
Sediment Basins 7/	100 to 300	10 to 30	26.30 to 78.80	-	60-95	25-50	2.77 to 29.20	10.50 to 420

NA = Not Applicable

1/ Cost and effectiveness estimates based on review of the literature is presented in Appendix A.

2/ Includes costs associated with physical outlays as well as changes in yield.

3/ Sediment losses before implementation of each BMP are estimated to range from 3 to 20 tons per acre.

4/ Phosphorus losses before implementation of each BMP are estimated to range from 0.5 to 10 pounds per acre.

5/ Cost-effectiveness estimates are calculated using the midpoint of the annualized cost range estimate for each BMP.

6/ Grassed waterway costs are estimated on the assumption that one acre of grassed waterway will serve 75 acres of cropland.

7/ Sediment basin costs are estimated on the assumption that each basin serves 8 acres of cropland.

A. Conservation Tillage

The common element in various definitions of conservation tillage is the presence of crop residues on the soil surface to reduce water and wind erosion. The plant residue also serves to increase retention of soil moisture. Conservation tillage systems disturb or invert the soil less than conventional tillage.

1. Effectiveness

Most of the conservation tillage practices were designed for erosion control rather than nutrient management, but with decreases in soil loss there is usually a decrease in phosphorus leaving the field. Because soil lost to water and wind erosion is inversely related to the percentage of the soil surface covered by residue, conservation tillage is effective in reducing soil loss. The various forms of low till. (e.g., chisel, disking, ridge-planting) reduce soil loss in the range of 30-60 percent or 1-12 tons per acre whereas no-till generally results in reductions of 60-90 percent or 2-18 tons per acre (see, for example, Defiance Soil and Water Conservation District, 1984).

The impact on phosphorus loads reaching a stream from changing tillage systems is not quite as clear. The majority (e.g., 80 percent; Clark et al., 1985) of phosphorus in agricultural runoff is normally attached to sediment. Controlling sediment loss should also control phosphorus loss. However, with less tillage, fertilizer that is not drilled or banded into the soil is more likely to get carried away in runoff. Even so, low till practices generally reduce phosphorus loss by 25-50 percent or 0.1-5.0 pounds per acre and no-till results in a 50-80 percent reduction or 0.3-8.0 sounds per acre (U.S. Corps of Engineers, 1981; Logan and Adams, 1981; Logan and Forster, 1982; Mueller et al., 1983).

2. Costs

The annualized net investment cost stemming from the purchase of new machinery complements (i.e., chisel plow, drill) is effectively zero since the machinery needed for each type of tillage is comparable in cost. In fact, net long-run investment costs may be negative for conservation tillage. With fewer field operations per year with conservation tillage, a smaller equipment inventory may be adequate if all land can be managed with conservation tillage practices.

Operating costs and yields (returns) are also affected by changes in tillage systems. Machinery labor and expenses for fuel, oil, and repairs decrease as tillage decreases. The inverse may be true with herbicide costs, if additional herbicides are required as tillage decreases. In general, operation and maintenance costs decrease from conventional tillage by about 3 percent (or $3 to $7.50 per acre) for the various forms of "reduced tillage" and about 7 percent ($5 to $15 per acre) with no-till. Yields can increase, decrease or remain constant depending upon soil series, climatic conditions, management techniques and timing. Yield variances of ± 10 percent for both corn and soybeans have been reported in the literature (see, for example, Defiance Soil and Water Conservation District, 1984; Griffith et al., 1977).

3. Cost-effectiveness

Given the above assumptions, and the cost and effectiveness ranges, it is possible to estimate a cost range per unit of soil and phosphorus saved. This cost-effectiveness is based upon the midpoint of the cost range estimate for implementing conservation tillage (-$3 to -$7.50 for low till, and -$5 to -$15 for no-till), the yield variance and the effectiveness range. 2/ When cost-effectiveness estimates are negative, the estimates are presented as "<0" rather than a specifically quantified estimate.

2/ The yield variance is based on crop budgets presented in Table III-1 (corn) and Table III-2 (soybeans). In these budgets, receipts are $300 and $220 per acre for corn and soybeans, respectively.

Cost-effectiveness range estimates are shown below.

Result	Item	Cost-effectiveness range estimates 1985 dollars/pound
Corn		
Low till 10% yield decrease	Soil	2.10 to 27.50
Low till 10% yield increase	Soil	< 0
No till 10% yield decrease	Soil	1.10 11.10
No till 10% yield increase	Soil	<0
Low till 10% yield decrease	Phosphorus	5.00 to 198
Low till 10% yield increase	Phosphorus	< 0
No till 10% yield decrease	Phosphorus	2.50 to 80
No till 10% yield increase	Phosphorus	<0
Soybeans		
Low till 10% yield decrease	Soil	1.40 to 18.60
Low till 10% yield increase	Soil	<0
No till 10% yield decrease	Soil	0.70 to 6.70
No till 10% yield increase	Soil	<0
Low till 10% yield decrease	Phosphorus	3.40 to 134
Low till 10% yield increase	Phosphorus	<0
No till 10% yield decrease	Phosphorus	1.50 to 48
No till 10% yield increase	Phosphorus	<0

B. Contouring

Contouring is a reasonably inexpensive BMP to implement; at the same time, it is very effective in reducing large quantities of soil and phosphorus losses. Generally, contouring is practiced in conjunction with other BMPs including conservation tillage, strip cropping, and terracing. Accordingly, the cost-effectiveness of contouring in reducing soil and phosphorus losses is difficult to estimate. However, some general conclusions can be drawn.

1. Effectiveness

The effectiveness of contouring in reducing soil and phosphorus losses is somewhat difficult to estimate because so many site-specific factors are involved. Accordingly, a discussion of effectiveness can only be made with certain assumptions regarding the field to be contoured. First, contouring is typically implemented on land with a slope ranging from 2 to 8 percent. On land with slopes less than 2 percent, soil erosion is not generally a problem; on slopes with more than an 8 percent grade, other practices (e.g., terracing) are more appropriate as contouring becomes much less effective.

Length of slope is also important in estimating the effectiveness of contouring. When rainfall exceeds surface detention and infiltration, contoured rows may be washed, over by runoff. Generally, the maximum slope length varies inversely with grade of slope. For example, on fields with a 2 percent slope, contouring is generally considered effective on slope lengths up to 400 feet; conversely, on fields with an 8 percent slope, contouring is generally considered effective on slope lengths up to 200. feet (for more detail, see Stewart et al., 1975).

Rainfall patterns also influence the quantity of soil and phosphorus lost from a contoured field. Of importance is not only the quantity of rainfall but also the intensity with which rainfall occurs; together these factors determine rainfall erosivity. With other factors being equal, the greater the rainfall erosivity, the greater are the losses of soil and phosphorus; this is true regardless of which BMPs are implemented. Generally, in EPA Region V, rainfall erosivity increases from north to south (Wischmeier and Smith, 1978).

In addition to slope and rainfall patterns, soil type also affects the absolute quantity of soil and phosphorus lost from a given field, and accordingly the cost-effectiveness of contouring. Generally, contouring is more effective on soils that readily allow water infiltration, have large particle sizes and are still reasonably cohesive. Contouring on poorly drained soils can actually aggravate wetness problems.

The type of crop grown will also influence the effectiveness of contouring. For example, larger losses of soil and phosphorus are typical with(for) row crops than with(for) closely planted crops such as small grains. However, percentage reductions of soil and phosphorus losses should be comparable on row crops versus closely planted crops on contour and straight tilled fields (see, for example, Johnson and Moore, 1978; Bedell et al., 1946).

Finally, the quantity of phosphorus in the upper levels of the soil profile will also affect the absolute quantity of phosphorus losses. The higher the phosphorus content in the soil profile, the higher the potential phosphorus loss.

Given the general conditions delineated regarding slope and slope length, contouring can reduce soil losses by 40 to 80 percent and phosphorus losses by 35 to 75 percent. Depending on rainfall patterns, soil type, and crop, contouring will reduce soil losses in the range of 1.2 to 16 tons per acre per year; similarly phosphorus losses will normally be reduced by 0.2 to 7.5 pounds per acre per year (see, for example, Bedell et al., 1946; Van Doren et al., 1970; International Joint Commission, 1983).

2. Costs

Contouring cost estimates are reasonably easy to assess. The principal costs are associated with reduced machinery and labor efficiency resulting from irregular field tillage. Although deviations will exist, operating, and maintenance costs will generally be in the range of $3 to $6 per acre as supported in the literature (see, for example, Toups Corp., 1977; Smith, et al., 1979; Quinn et al., 1984). Operating and maintenance costs will be at the lower end of this range when contours are reasonably uniform throughout the length of the field. When contours are more irregular, operating and maintenance costs will be in the upper end of the estimated range.

Contouring investments are relatively modest, with' surveying to determine the proper layout of contours being the principal component. Investment costs typically will range from $3 to $12 per acre. Costs will vary depending on topography (the more variable, the higher the cost) and the sophistication with which the contours are laid out. Additionally, contouring will have a higher investment cost when strip cropping is implemented in conjunction with contouring. Annualized investment and operating and maintenance costs for contouring (based on an expected investment life of 10 years) are estimated to range from approximately $3.50 to $8.00 per acre.

Potential yield increases could effectively negate the cost increases associated with contouring. However, yield increases are not well documented in EPA Region V with only one study showing yield changes (Van Doren et al., 1950); hence, for purposes of this analysis, yield changes under contouring are considered negligible.

3. Cost-effectiveness

As indicated in the previous two sections, costs associated with contour tillage and its effectiveness in reducing soil and phosphorus losses vary considerably depending on site-specific conditions. By using the midpoint of the cost range estimate ($3.50 to $8.00 per acre) and the range estimates for soil and phosphorus reductions resulting from contouring, the cost-effectiveness estimates are calculated and presented below.

Item	Cost-effectiveness range estimates for contouring 1985 dollars/acre/year
Soil	$0.36 to $4.79 per ton
Phosphorus	$0.77 to $32.86 per pound

C. Terraces

Terracing is another support practice that is generally used in conjunction with other management practices such as conservation tillage. Terraces are designed to reduce effective slope length and runoff concentration thereby reducing erosion. A terrace is an earthen embankment, channel, or combination of ridge and channel constructed parallel to the slope of a field.

1. Effectiveness

In addition to allowing time for soil particles (and the nutrients therein) to settle out of suspension, ponding of runoff behind terraces can increase infiltration and therefore reduce surface runoff. Information reviewed indicates that soil loss is generally reduced by 50 to 90 percent (with more occurrences in the 70 to 90 percent range) or 1.5 to 18 tons per acre (see, for example, META, 1979; Haith and Loehr, 1979; Bos, 1983; Starr, 1983).

Reductions in phosphorus loss can also be quite high at 50 to 75 percent or 0.25 to 7.5 pounds per acre (see, for example, Burwell et al., 1974; Haith and Loehr, 1979; International Joint Commission, 1983). There may be a potential trade-off to be examined, however. Because terraces retain soil on the land, they do reduce losses of adsorbed substances such as phosphorus. With the runoff being held on the land for a longer period of time, there may be actual increases in the loss of soluble phosphorus to the ground water below the terraced field. Research up to this time has been inconclusive.

2. Costs

Terraces are usually constructed on land with up to a 12 percent slope. Beyond that grade they are considered impractical because the steeper backslopes tend to negate the benefits of the terrace (see, for example, Burwell, 1974; Haith and Loehr, 1979): Because each terrace installation must be designed to meet the particular characteristics of that site, costs of terracing are very site specific and cover a broad range. Based upon the literature reviewed and information provided by Soil Conservation Service (SCS) officials, establishment costs for terracing are estimated to range from $0.35 to $2.40/foot (Lake and Morrison, 1977; Haith and Loehr, 1979; Lewis, 1985). Though there is no fixed ratio for feet of terrace per acre of land, a reasonable range is 175 to 300 linear feet of terrace per acre. This implies an average per acre cost of $61.25 to $720. Higher capital costs stem from terraces which are narrower and steeper.

Upkeep of the outlet and periodical removal of sedimentation from the channel are necessary maintenance operations with terraces. Five percent of the original investment costs per year is generally estimated for these operations. Thus, operation and maintenance costs range from approximately $3 to $36 per acre. Upkeep of the terrace and its outlet will influence its life and hence, its cost-effectiveness (META, 1979; Bos, 1983; EPA Report to Congress, 1984).

As with other BMPs, crop yields may decrease, increase or remain constant after terraces are installed. Again it is dependent upon the climate and soil characteristics, with yields increasing in dry, arid areas when terraces are used. It should also be noted that the acreage base is reduced with some terraces as land required for the water channel and terrace cannot be planted (META, 1979; Starr, 1983).

Terraces, if properly constructed and maintained, may be expected to have a life expectancy of approximately 20 years. The total annualized cost of terraces per acre of land, given the above estimates, ranges from approximately $10.20 to $120.64.

<u>3. Cost-effectiveness</u>

Given the ranges and assumptions, and using the midpoint, annualized cost estimate of $65.40 an acre, the cost-effectiveness range is presented below.

Item	Cost-effectiveness Range 1985 dollars/acre/year
Soil	$3.63 to $43.60 per ton
Phosphorus	$8.72 to $261.60 per pound

D. Grassed Waterways

Grassed waterways are natural or constructed vegetated depressions which retain and redirect runoff water while preventing the formation of rills or gullies. Grassed waterways reduce erosion more than runoff volume and thus are best used in conjunction with other runoff reducing practices such as conservation tillage and contouring.

1. Effectiveness

Reducing the sediment load leaving a field with the use of a grassed waterway can be quite effective. Although some of the reduction is due to elimination of erosion in the waterway itself, much of the reduction is due to deposition in and along the waterway. Under typical conditions grassed waterways reduce sedimentation about 60 to 80 percent or 2 to 16 tons per acre (see, for example, Foster et al., 1979; Logan and Forster, 1982; Bos, 1983).

Reductions in phosphorus losses based on a review of the literature are estimated to be approximately 40 to 50 percent (0.20 to 5 pounds per acre). This lower reduction, compared to sediment control, is due to the fact that there is still considerable runoff and thus soluble phosphorus losses. Because of this, grassed waterways are most effective when used in conjunction with a management practice such as conservation tillage.

Vegetation type and topography of the drained area are considered to be the critical factors in determining effectiveness of grassed waterways.

2. Costs

Costs for grassed waterways are quite site-specific, as size of the waterways are a function of the watershed slope and acres drained. Estimates by SCS officials and other researchers place the investment costs of grassed waterways between $1,200 and $3,000 per acre of grassed waterway (Lake and Morrison, 1977; Logan and Forster, 1982; Clark, 1985; Lewis, 1985). One acre of grassed waterway will service approximately 75 acres of croplands, so the implicit cost per acre ranges from $16 to $40. This cost is comprised of earthmoving and shaping, seeding and fertilizing expenses. As with terraces; annual operation and maintenance costs are estimated to be about 5 percent of the initial investment (Humenik et al., 1983) generally ranging from $0.80 to $2.00 per year for each acre of cropland served. Total annualized costs for grassed waterways, based on an expected investment life of 20 years, are $2.70 to $6.70 per acre.

Grassed waterways have no direct effect on crop yields. However, some of the acreage base for growing crops is reduced since the grassed waterway itself only provides forage.

3. Cost-effectiveness

Again, the cost-effectiveness is calculated from the midpoint of the annualized cost range estimate of $2.70 to $6.70 for grassed waterways, and the reductions in soil and phosphorus losses presented above. These cost-effectiveness estimates are based on the assumption that one acre of grassed waterway will serve 75 acres of cropland.

Item	Cost-effectiveness Range 1985 dollars/acre/year
Soil	$0.29 to $2.61 per ton
Phosphorus	$0.94 to $23.50 per pound

E. Fertilizer Management

While fertilizers are not major contributors of nutrients to water bodies (Crosson, 1983); reducing the amount of fertilizer applied or the vulnerability of fertilizer to runoff can help to diminish the rate of eutrophication in surface water and ground water.

1. Effectiveness

In the Great Lakes Basin, excessive fertilization with phosphorus may cause higher levels of nutrient runoff into surface waters. The effectiveness of fertilizer management practices therefore depends on fertilizer application rates, methods of application, timing of applications, soil characteristics and crops grown. Unfortunately, no estimates on reductions in phosphorus loads are available. As a result, cost-effectiveness estimates cannot be provided.

2. Costs

Cost associated with fertilizer management are generally either for soil testing or increased costs associated with alternative application procedures. State extension services generally recommend soil tests every three years, with a single test recommended for every 30 to 45 acres harvested; accordingly, the annual cost per acre for soil testing is negligible.

Costs associated with injecting or otherwise incorporating phosphate fertilizers are also relatively minor. Generally, the additional costs would be in the range of $1 to $5 per acre per year. Costs for split applications would be in the upper end of this range.

F. Sediment Basins

Sediment basins are catchments designed to impound agricultural runoff water long enough for suspended sediment and adsorbed nutrients to settle out. These ponds, designed to collect pollutants after they leave the field but before they can cause environmental damage, are typically constructed along a stream or between a field and a waterway.

1. Effectiveness

The effectiveness of sediment basins in reducing nonpoint pollution depends on the design criterion, i.e., the relationship between the sediment basin's volume and the volume of water flowing through it in a particular storm. The larger the basin relative to inflow, the greater the effectiveness of the basin.

Sediment removal efficiencies have reportedly been greater than 90 percent when basins are properly constructed and maintained (Dendy, 1974; Robbins and Carter, 1975). However, sediment removal efficiencies are more typically in the range of 60 to 95 percent (Brown et al., 1981; Box, 1983) or 1.8 to 19 tons per acre per year.

Phosphorus removal efficiency through the use of sediment basins is somewhat lower than sediment removal. This is due to the fact that soluble phosphorus is not controlled by sediment basins. Also, a relatively large amount of phosphorus is adsorbed to small clay particles which do not readily settle out (Brown et al., 1981). Typically, sediment basins are effective in removing from 25 to 50 percent of total phosphorus from stormwater runoff (Brown et al., 1981, Bos, 1983).

2. Costs

The cost of constructing and maintaining sediment basins is often cited as their major disadvantage. Sediment basin size is a major cost-determining factor and is dependent on several variables including frequency and intensity of rainfall, area drained, soil type, and topography. Sediment basin size is usually expressed in terms of the area drained. Typical basins in the Great Lakes region serve from 5 to 10 acres. Construction costs include earthwork and outlet construction, and range from $1,000 to $1,500 per structure for basins serving 5 to 10 acres (Hemmer, 1985).

Operating and maintenance costs are approximately 10 percent of the construction cost per year (Hemmer, 1985). Maintenance activities include mowing vegetative cover in and around the basin and periodically cleaning out material that has accumulated in the basin. This latter activity is important for maintaining the basin's suspended solids removal efficiency. The number of times. a basin needs cleaning depends on the amount of rainfall and the number of major storms. Basins may need cleaning several times per year or several years may elapse before dredging is necessary. In the Great Lakes basin a typical timeframe is one cleaning for every one to three years.

Sediment basins are expected to have a life of 10 years with appropriate maintenence (Hemmer, 1985; Halverson, 1986). Assuming a typical basin serves 5 to 10 acres and costs from $1,000 to $1,500 to construct, total annualized costs would range from $26.30 to $78.80 per acre per year.

3. Cost-effectiveness

Given the ranges of effectiveness and the midpoint of annualized cost of $52.55 per acre per year the cost-effectiveness range is presented below.

Item	Cost-effectiveness Range 1985 dollars/acre/year
Soil	$2.77 to $29.20
Phosphorus	$10.50 to $420.00

G. Livestock Exclusions

As with many of the agricultural BMPs, the costs of implementing livestock exclusions is highly variable by site. Similarly, the effectiveness of livestock exclusions in reducing nonpoint phosphorus loadings to streams is dependent on the physical characteristics of the site; unfortunately, few quantitative estimates are available regarding the effectiveness of livestock exclusions. Nevertheless, some general conclusions can be drawn.

1. Effectiveness

Factors which contribute to the general effectiveness of livestock exclusions are slope of streambank, accessibility of the stream by livestock, streambank soil stability, stream flow and variation in stream flow, and the ability of the stream in question to assimilate contaminants.

No estimates of the effectiveness of livestock exclusions in reducing nonpoint phosphorus loadings in streams are available for the Great Lakes Basin. Estimates from the livestock exclusion Rural Clean Water Program (RCWP) experiment in Florida will be forthcoming; however, data are not currently available (Ritter, 1985), While it has been estimated that phosphorus load reductions in excess of 30 percent can be expected from adoption of livestock exclusions (Bos, 1983), no more definitive estimates are available. As a result, cost-effectiveness estimates cannot be provided.

2. Costs

While the cost of livestock exclusions is dependent on the physical and topographical setting, costs can be estimated for a typical situation. For example, a quarter section (160 acre) pasture with a stream running through the middle would require fencing on both sides of the stream, a distance of approximately one mile. Total estimated investment costs, based on SCS estimates, are in the range of $2,100 to $2,400 per mile of fence. Additional investment costs would also be necessary for two access ramps, at a total cost of $500 to $1,000. Operation and maintenance costs for both the fence and water access ramps are estimated to be 5 percent of total investment costs or approximately $130 to $170 per year (Hemmer, 1985).

With an estimated life for both the fencing and water access ramps of 20 years, total annualized costs are estimated to range from approximately $375 to $490 per year in this hypothetical example.

H. Feedlot Runoff Waste Management

Feedlot runoff control systems generally consist of a diversion that prohibits the entry of unpolluted water into the feedlot, a collection and storage (settling basin/detention pond) system where most of the pollutants are separated from the water and a dispersion system for the effluent. A dispersion system which involves applying the effluent via irrigation to cropland is sometimes referred to as a zero discharge system; another dispersion system which consists of a sloped vegetated area through which the effluent is forced to flow is called a vegetative filter system (Vanderholm et al., 1979).

The costs and effectiveness of feedlot runoff waste management are examined in this section, based on a review of the literature. For purposes of this analysis, estimates for 100, 500 and 1,000 head beef feedlots with vegetative filter runoff control systems are presented. (According to the literature reviewed, zero discharge systems are not as cost-effective as the vegetative filter systems in controlling phosphorus pollution.) No allowances are made in this analysis for the value of the nutrients saved from the waste management system.

1. Effectiveness

Vegetative filter systems are quite effective in preventing considerable quantities of pollutants from entering surface waters. Under typical conditions, approximately 80 to 90 percent of solids and 70 to 95 percent of phosphorus will be controlled via a vegetative filter feedlot runoff control system (see, for example, Sutton et al., 1976; Vanderholm et al., 1979; and Young et al., 1980).

Actual quantities of phosphorus and solids contained in runoff is highly variable from location to location as well as from year to year (Madden and Dornbush, 1971). Consequently, typical values are difficult to predict.

However, based on published research, typical annual phosphorus runoff losses are estimated to range from 1.5 to 5.0 pounds per 1,000-pound cow (Young et al., 1980; Vanderholm et al., 1979; and Madden and Dornbush, 1971).

2. Costs

Costs for the feedlot runoff control system are directly related to feedlot size. In addition, costs will vary depending on site-specific factors such as topography, climate (especially rainfall patterns) and other factors such as management of the feedlot and type of system installed.

Investment costs associated with vegetative filter feedlot runoff controls include earth moving, settling basin construction costs and development of a vegetative filter. Major operating and maintenence costs are expenditures for repair, taxes, insurance and labor.

Investment, operating and maintenence and total annualized cost range. estimates (based on expected life of 20 years) are presented below. These cost estimates are based on several studies including David et al., 1973; Pherson, 1974; Buxton and Ziegler, 1974; Johnson and Davis, 1975; Miner et al., 1970; Vanderholm et al., 1979; and Young et al., 1980.

Feedlot capacity (head)	Cost ranges: Investment	O&M	Annualized
	(1985 dollars)		
100	5,000 - 12,000	300 - 600	890 - 2,010
500	9,000 - 16,000	400 - 800	1,460 - 2,680
1000	11,000 - 20,000	500 - 1,000	1,790 - 3,350

3. Cost-effectiveness

The cost-effectiveness estimates of vegetative filters in reducing phosphorus pollution, calculated from the midpoint of the annualized cost estimates, are presented below.

Feedlot capacity (head)	Cost-effectiveness range (1985 dollars/pound of phosphorus)
100	3.05 - 13.80
500	0.90 - 3.95
1000	0.55 - 2.45

III. COST-EFFECTIVENESS OF CONSERVATION TILLAGE IN REDUCING PHOSPHORUS POLLUTION -- THE HONEY CREEK CASE STUDY

In this chapter, the cost-effectiveness of conservation tillage in reducing nonpoint phosphorus pollution is examined for a specific watershed. The results from this case study of the Honey Creek watershed in north central Ohio are subsequently compared with POTW cost-effectiveness estimates for the Great Lakes region developed and presented in Chapter IV. A map depicting the relationship between the watershed and part of the Lake Erie drainage is presented in Figure III-1.

Conservation tillage is a widely publicized agricultural management practice that relies on tillage practices which leave substantial quantities of organic matter on the soil surface. The environmental consequences of this practice are decreased losses in sediment and nutrients -- of which phosphorus is the primary concern of this study -- and potentially increased levels of pesticide pollution in both surface and ground waters. Because of the increased threat of pesticide pollution, the consequences of basin-wide adoption of conservation tillage are examined in this case study. Furthermore, because of the variable nature of storm events which affect the reliability of conservation tillage in controlling phosphorus losses (as well as the potential for pesticide pollution damage), probability distributions for these factors are also incorporated into the case study.

This chapter is comprised of four major sections. The first section summarizes the background and approach taken for the case study. Modeling considerations and development, with emphasis on the linear programing model, are then presented. The data used in the analysis are presented in the third section with the cost-effectiveness estimates presented in the final section.

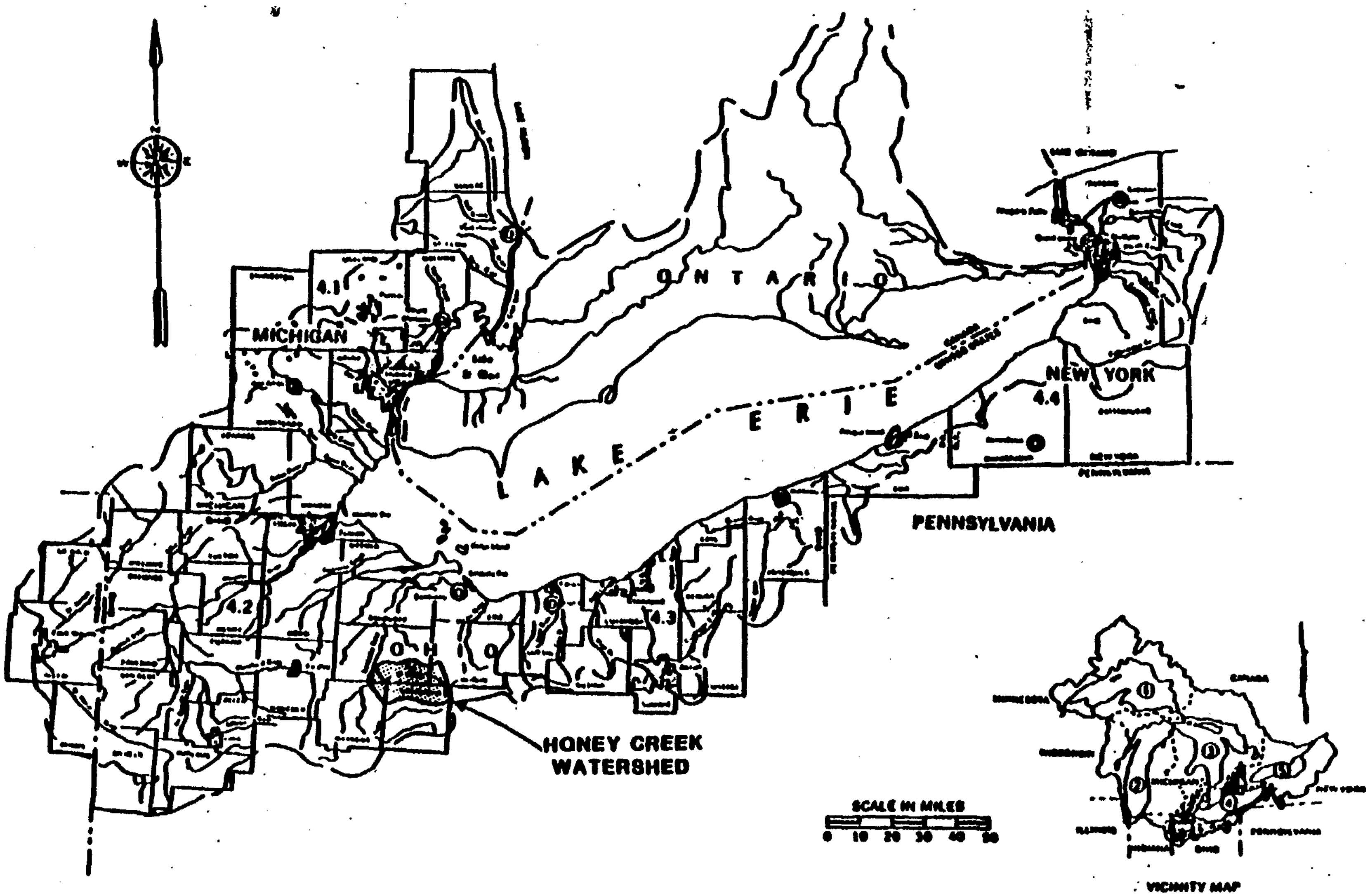

Figure III-1. The Honey Creek watershed in relation to partial drainage of Lake Erie.

A. Background and General Approach

The Honey Creek basin is a 392 sq. km (151 sq. mi.) agricultural watershed in the Lake Erie drainage basin of north central Ohio; the watershed is located in Seneca, Huron and Crawford counties. A 1979 land use inventory indicated that approximately 82% of the basin was in agricultural use, with row crops (corn and soybeans) being the predominant crops (Cahill et al., 1979). Like much of the other agricultural land in the Lake Erie drainage basin, storm runoff from the watershed has been identified as a source of phosphorus loads to Lake Erie. In addition, monitoring studies have identified pesticide concentrations in Honey Creek surface waters and nearby public drinking water supplies (Baker, 1985); The U.S. Army Corps of Engineers targeted the Lake Erie drainage basin, and Honey Creek in particular, for special nonpoint source control programs using conservation tillage to reduce phosphorus loadings. The Corps' study, which relied heavily on the ability of local farmers to successfully apply conservation tillage practices, took place during the three-year period from 1979 to 1982 (U.S. Army Corps of Engineers, 1982).

Because the Honey Creek basin has been a field demonstration and research watershed for conservation tillage controls, a great deal. of agronomic, economic and water quality data are available. This suggests a logical starting point for developing detailed edge-of-stream cost-effectiveness estimates for phosphorus removal using actual test data. Area-specific crop budgets were developed from the 1979-1985 conservation tillage demonstration reports. These reports were developed by the local Soil and Water Conservation District, from information developed by Soil and Water Conservation District personnel, and statewide enterprise budgets developed by the Ohio State University Extension Service. Budget data for each crop and rotation pattern included the quantity and timing of all nutrient, herbicide and insecticide applications to the land unit (acre).

Production activities described in the model were continuous and rotating cultivation of corn or soybeans using conventional, reduced and no-till practices and a corn-soybean rotation using the three methods of tillage. These tillage practices are delineated on the basis of the amount of plant residue left on the field and the extent of soil disturbance (Duffy and Hanthorn, 1984). Conventional till includes primary and secondary tillage for seedbed preparation and cultivation resulting in complete loss or burial of crop residue. Reduced till involves less surface disruption with increased herbicide use for weed control and a minimum 30 percent crop residue remaining at planting time. No-till practices leave a high percent of crop residue and rely more heavily on herbicides, disturbing only a small part of the land surface. Permanent pasture (hay) was also included as a nonpoint control activity. Because conservation tillage is the primary focus of regulatory control in this area, alternative BMPs are not considered in this study.

Cropland soils in the basin were classified into productivity groups based primarily on soil moisture characteristics and the adaptability of the soils to row crop conservation tillage practices (Cahill et al., 1979). These groups were broadly defined as: well drained and always suitable for conservation tillage (Class I, 9.2 percent); moderately well drained and suitable for conservation tillage with late planting (Class II, 39.9 percent); suitable for conservation tillage only with adequate drainage (Class III, 37.7 percent); and poorly drained and unsuitable for conservation tillage (Class IV, 13.2 percent). Yield increases were estimated for reduced and no-till applications on Class I and II soils on the basis of demonstration plot results for the basin. Demonstration plot results also provided the basis for estimating decreased yields on Class III and IV soils with conservation tillage.

B. Modeling Considerations and Development

Agricultural nonpoint pollution is a complex process involving the transport, fate and effects of multiple natural and synthetic substances in surface and ground waters. Since nonpoint sources are extremely difficult and expensive to quantify on a field trial basis, mathematical models are frequently used. Mathematical models which attempt to simulate this complex process inevitably require tradeoffs between spatial scale, edaphic detail, pollutants considered, hydrologic features, water quality indicators and the temporal behavior of this process. Most studies to date of the economic cost of nonpoint pollution controls have used deterministic (linear programming) models representing steady state conditions. Typically these models are either field or watershed scale.

Field level studies have generally focused on gross soil loss using the Universal Soil Loss Equation (USLE) as the primary model of the surface erosion process. The USLE predicts gross soil loss per acre for various soil types and terrains based on long-term average precipitation for different regions of the country. Nutrient (phosphorus and nitrogen) losses are usually assumed to be a fixed fraction of soil loss. Crowder et al. (1984) used a more advanced field scale model to simulate annual edge-of-field losses for sediment, nutrients and pesticides under daily precipitation conditions. Watershed level studies of nonpoint control costs have considered sediment losses (Lovejoy et al., 1985) and sediment with nutrient losses (Kramer et al., 1984). Neither field nor watershed level studies have related field losses to receiving surface or ground water quality, although Chapra et al. (1983) have used a model to convert nonpoint surface water loads to total phosphorus concentrations in the Great Lakes.

Inherent in these nonpoint source modeling efforts is the premise that long-term average (expected value) loads and/or concentrations are the appropriate control variable for water quality regulation. If the pollutant load distribution is normally distributed (i.e., 50 percent of the observations are above the average value and 50 percent are below and the distribution is not skewed), this approach ignores the fact that nonpoint controls would not achieve expected annual load reductions 50 percent of the time. Conversely, point source controls are designed to meet specific pollutant removal levels and reliability criteria consistent with government regulations. Point source controls consider the cost and likelihood of achieving water quality objectives. Given that nonpoint loads are primarily event-related phenomena that deliver pulses of varying mixture and concentration of pollutants to surface and ground waters, a more comprehensive modeling framework is required to provide planning information about the cost of controlling these stochastic discharges.

1. Modeling of Pesticide and Phosphorus Loading Functions

EPA analysts developed estimates of pesticide and phosphorus loading functions for alternative agricultural land use practices in the Honey Creek watershed (Milon, undated). An integrated watershed simulation model was used to generate probability distributions for both pesticides and phosphorus. The probabilistic methodology was used in order to provide a realistic basis to test the cost-effectiveness of BMPs in controlling intermittent nonpoint source loads and a consistent framework for comparing the cost-effectiveness of non-stochastic point source controls (e.g., POTWs).

To demonstrate the stochastic control framework, surface runoff and soil infiltration models were combined to estimate expected values and distributions of the transfer coefficients for alternative BMP controls on agricultural chemicals in surface water and groundwater in an agricultural watershed. The Pesticide Root Zone Model (PRZM) (Carsel et al., 1984) was the primary model used to simulate the land/soil phase of BMP controls. PRZM is a dynamic finite-difference model of chemical fate and transport through the soil profile to groundwater and through runoff to surface water. The soil profile is represented as a series of layered compartments within which advection, dispersion, degradation, and plant uptake are represented. Daily water balance calculations are used to determine runoff, evapotranspiration and infiltration. The calculated runoff volume is used to estimate (gross) erosion losses; both runoff and erosion were used to estimate surface pesticide loads.

Runoff and erosion loads, as developed through use of PRZM, were used by EPA analysts (Milon, undated) with the Stream Transport and Agricultural Runoff of Pesticides for Exposure Assessment: A Methodology (STREAM) (Donigian et al., 1984) modeling procedures to determine surface water pesticide concentrations at a watershed outlet. STREAM estimates the exceedance probabilities for pesticide concentrations with alternative runoff event durations (1, 2, 4 and 30 day durations).

To calculate pesticide concentrations in groundwater, pesticide loads from PRZM were input by EPA analysts (Milon, undated) to the groundwater model originally developed by Yeh (1981). This model is designed to simulate pulse inputs of contaminants such as those from agricultural nonpoint sources.

Both PRZM and STREAM are primarily pesticide/sediment/runoff models that do not consider nutrient loads. In this application, simulation results on stream channel sedimentation from the Hydrological Simulation Program-Fortran (HSPF) were used with event based loading functions developed by Haith and Tubbs (1981) to estimate nutrient (phosphorus and nitrogen) transfer coefficients for surface and ground waters (Milon, undated).

The use of these models resulted in estimates of edge-of-stream phosphorus loadings for the different crops and tillage practices. Phosphorus loading estimates were derived for four reliability thresholds: 50, 60, 75 and 95 percent. 1/

Finally, through study of the fate and transport of pesticides under the different crops and tillage practices, restrictions in pesticide usage

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1/ Phosphorus loading estimates are based on a probability distribution. For example, with the phosphorus load value (in pounds per acre of cropland) corresponding with the 95 percent reliability threshold, actual phosphorus loadings would be at or below the estimated quantity 95 percent of the time. Interpretation of the other thresholds is the same. Assuming normality of the phosphorus loading probability distribution, the 50 percent reliability threshold would actually be the expected long-term average phosphorus loading.

necessary to meet drinking water standards were estimated. Crop production costs and returns were then estimated under two pesticide restriction levels. 2/ These data were used in the linear programing model, described below, to estimate the cost-effectiveness of conservation tillage in reducing phosphorus loadings, subject to pesticide usage constraints.

2. Linear Programming Model

The phosphorus loading estimates and the crop production budgets which are presented in the following section are inputs to a linear programing model used to estimate the cost-effectiveness of achieving phosphorus load reductions with conservation tillage. Linear programing (LP) is a planning method that is helpful in decisions requiring a choice among alternatives given a set of constraints. Three components of a linear programing model are: 1) an objective function (in this case income maximization); 2) restrictions which typically take the form of resource limitations (e.g., available crop acreage and phosphorus loading restrictions); and 3) alternative combinations of these resources in the production process. An LP model maximizes or minimizes the objective function subject to these specific constraints. A linear programing model for a maximization problem may be written as:

$$\text{maximize } Z = C_1 X_1 + C_2 X_2 + \ldots + C_n X_n \qquad (1)$$

subject to the input-output relationships and the resource levels:

$$\begin{aligned} a_{11} x_1 + a_{12} x_2 + \ldots + a_{1n} x_n &\le b_1 \\ a_{21} x_1 + a_{22} x_2 + \ldots + a_{2n} x_n &\le b_2 \\ \vdots \qquad \vdots \qquad & \vdots \quad \vdots \\ a_{m1} x_1 + a_{m2} x_2 + \ldots + a_{mn} x_n &\le b_m \qquad (2) \end{aligned}$$

$$x_1 \ge 0, x_2 \ge 0, \ldots x_n \ge 0 \qquad (2.1)$$

2/ Pesticide restriction levels were set so that Recommended Maximum Contamination Levels (RMCLs) for pesticides were met with (1) 50 percent reliability, and (2) 95 percent reliability.

In a compact form the problem can be rewritten as:

$$\text{maximize } Z = \sum_{j=1}^{n} C_j X_j \qquad (1a)$$

subject to:

$$\sum_{j=1}^{n} a_{ij} X_j \leq b_i \text{ for all } i \qquad (2a)$$

$$X_j \geq 0 \text{ for all } j \qquad (2.1a)$$

where

i = 1 , 2 , ... m resources and j = 1, 2, ... n activities,

Z = the objective function,

C_j = per unit prices, net incomes, or costs of associated activities

X_j = the possible level of alternative activities,

a_{ij} = the requirements of resource i per unit of activity j,

and

b_i = the resource availabilities of the m resources.

The objective function for this linear programing model. developed for the Honey Creek watershed was to maximize returns to land and management given constraints on total acreage, acreage of various enterprises, and phosphorus loading. Returns to management and land was deemed a more appropriate objective value than net income because management is a somewhat arbitrary figure in enterprise budgets, and land values vary substantially between states and regions. Therefore, sensitivity of the model to site location was reduced. These LP model data inputs are presented in the following section.

C. The Data

Two major data items are necessary as inputs into the LP model. First, the per acre return estimates for each crop enterprise are taken from crop production budgets and comprise the objective function(s) of the LP model. 3/ The second input is the phosphorus loss estimates for each crop enterprise associated with the various phosphorus control reliability levels. These estimates along with available acreage, make up the constraints for the LP model. Both data items are discussed in this section.

1. Crop Production Budgets

Crop production budgets for the Honey Creek watershed were developed from several sources. Yield data were derived from conservation tillage field demonstration projects conducted from 1979 through 1985 by the local Soil and Water Conservation District. Estimates of variable costs including seed, fertilizer, chemicals, fuel, trucking, repairs, etc. were obtained from Soil and Water Conservation District personnel and statewide enterprise production budgets as developed by the Ohio State University Extension Service. Other costs were also obtained from the statewide enterprise production budgets.

In this section three sets of crop production budgets are presented, corresponding to different pesticide contamination control levels. An analysis is also presented regarding the effects of implementing conservation tillage on the various land classes in the watershed.

a. Crop production budgets with no pesticide use restrictions

Tables III-1 and III-2 depict the enterprise budget for continuously planted corn and soybeans, respectively, in the Honey Creek watershed in 8985 under the three tillage practices. Table III-3 depicts the average annual receipts, costs and returns for corn and soybean rotations; this

3/ Three sets of crop production budgets were developed to specify three objective functions. The first set of budgets have no pesticide use restrictions. The final two sets of budgets depict pesticide restrictions sufficient to meet RMCLs with 50 and 95 percent reliability.

Table III-1. Ohio Extension Service continuous corn production budgets, 1985

Item	Explanation			Conventional Till	Reduced Till	No-Till
				------------1985 dollars/acre------------		
Receipts	2.50/bushel			$318	$310	$303
Yields (bushels)						
Conventional	Reduced	No-Till				
127	124	121				
Variable Costs						
Seed (kernels)	24.200k @	.90/1000	kernels	22	22	22
Fertilizer						
N	140 lbs @	.20/lb		28	28	28
P_2O_5	44 lbs @	.22/lb		10	10	10
K_2O	60 lbs @	.11/lb		7	7	7
Lime	1000 lbs @ 15.00/Ton			8	8	8
Chemicals						
Conventional	Reduced	No-Till				
Carbofuran - $12 Atrazine - $4 Alachlor - $10	Carbofuran - $12 Atrazine - $4 Alachlor - $13 Isotox - $1	Carbofuran - $12 Atrazine - $4 Alachlor - $15 Isotox - $1 Paraquat - $8		26	30	40
Fuel, Oil & Grease				18	14	12
Drying - Fuel and Electric Only .15/bu				18	18	18
Trucking - Fuel only				2	2	2
Repairs				18	16	14
Miscellaneous				12	12	12
Interest on Operating Capital				10	10	10
Total Variable Cost				179	177	183
Other Costs						
Labor Charge				15	12	9
Machine and Equipment Charge				50	50	50
Total Other Costs				65	62	59
Returns to Management and Land				74	71	61

Source: Eased on Ohio State University Extension Service enterprise budgets, Honey Creek watershed demonstration plot results and Personal communications with EPA officials.

Table III-2. Ohio Extension Service continuous soybean production budgets, 1985

Item	Explanation	Conventional Till	Reduced Till	No-Till
		1985 dollars/acre		
Receipts	5.80/bushel	$250	$238	$250
Yields (bushels): Conventional 43; Reduced 41; No-Till 43				
Variable Costs				
Seed	1 bu. @ 13.00/bu	13	13	13
Fertilizer				
P_2O_5	40 lbs @ .22/lb	9	9	9
K_2O	55 lbs @ .11/lb	6	6	6
Lime	1000 lbs @ 15.00/Ton	8	8	8
Manganese	6 lbs @ .20/lb	1	1	1
Chemicals				
	Conventional: Metribuzin - $12, Alachlor - $10; Reduced: Metribuzin - $12, Alachlor - $10, Paraquat - $8, Metalaxyl - $3; No-Till: Metribuzin - $16, Alachlor - $16, Paraquat - $8, Metalaxyl - $3	22	33	43
Fuel, Oil & Grease		18	14	12
Trucking - Fuel Only		1	1	1
Repairs		17	16	15
Miscellaneous		12	12	12
Interest on Operating Capital		7	8	8
Total Variable Cost		114	121	128
Other Costs				
Labor Charge		14	11	8
Machine and Equipment Charge		50	50	50
Total Other Costs		64	61	58
Returns to Management and Land		72	56	64

Source: Based on Ohio State University Extension Service enterprise budgets, Honey Creek watershed demonstration plot results and personal communications with EPA officials.

Table III-3. Ohio Extension Service production budgets for corn and soybean rotations, 1985

Item	Conventional Till	Reduced Till	No-Till
	------------1985	dollars/acre	-----------
Receipts 1/	284	273	277
Total Variable Cost Per Acre 2/	139	141	148
Total Other Costs 3/	65	62	59
Returns to Management and Land	80	70	70

1/ Based on the following yields and prices (discrepancies due to rounding):

	Price $/bushel	Conventional till	Reduced till	No-till
		------bushels/acre	for two year rotation	-----
Corn	2.50	127	123	119
Soybeans	5.80	43	42	44

2/ Variable costs per acre are the average costs associated with continuous corn and soybeans with the following adjustments:

- Corn in rotation requires $4 per acre less nitrogen and $12 per acre less chemicals (Carbofuran) than continuous corn

3/ Average of other costs incurred under continuous corn and soybeans under corresponding tillage practices

Source: Based on Ohio State University Extension Service enterprise budgets, Honey Creek watershed demonstration plot results and personal communications with EPA officials.

budget is essentially an average of the continuous corn and soybean budgets with adjustments in receipts corresponding to different yields, fertilizer and chemical costs as noted. Finally, Table III-4 represents the hay production budget; only one tillage practice is considered for hay. Tables III-1 through III-4 portray crop production receipts and costs without any restrictions on pesticide use.

b. Crop production budgets with pesticide use restrictions

As previously discussed, an objective of this study is to examine the effects of the different tillage practices on achieving oral exposure limits of pesticides in drinking water (surface and ground waters). Conservation tillage practices generally rely on additional pesticide applications which have raised concern about potential increased pollutant problems; for example, conservation tillage increases subsurface water recharge and the likelihood of ground water contamination (Hinkle, 1983). Similarly, conventional tillage, while requiring somewhat lower levels of pesticide application, generally results in higher levels of runoff which has the potential of causing environmental damage downstream. Consequently, the potential pollution problems in the Honey Creek watershed from various pesticide applications, ground water regeneration rates and surface water runoff rates associated with each tillage practice were examined through computer simulations. Complete details of the pesticide concentration estimation procedures are available in Donigian and Carsel (1985).

The results of this process indicated that drinking water quality standards --known as Recommended Maximum Contamination Levels (RMCLs) -- could be met by substituting alternative pesticides. Crop production budgets for continuous corn, continuous soybeans, and corn and soybeans in rotation are presented in Tables III-5 through III-7. (No pesticide use restrictions are required on hay because no pesticides are used.) As indicated, the only pesticide, change is a substitution of metolachlor for alachlor. The effects of this pesticide change were a modest increase in chemical costs

Table III-4. Ohio Extension Service hay production budget, 1985

Item	Explanation	1985 Dollars/ Acre
Receipts	3.5 tons $60/ton	$210
Variable Costs		
Seed		2
Fertilizer Application		5
N	65 lbs @ .20/lb	13
P_2O_5	20 lbs @ .22/lb	5
K_2O	170 lbs @ .11/lb	19
Lime	1000 lbs @ 15.00/ton	8
Fuel, Oil & Grease		23
Repairs		20
Miscellaneous		15
Interest on Operating Capital		8
Total Variable Cost		118
Other Costs		
Labor Charge		23
Machine and Equipment Charge		48
Total Other Costs		71
Returns to Management and Land		21

Source: Based on Ohio State University Extension Service enterprise budgets, Honey Creek watershed demonstration plot results and personal communications with EPA officials.

Table III-5. Ohio Extension Service continuous corn production budgets, 1985, with pesticide use restrictions sufficient to meet Recommended Maximum Contamination Levels with a 50 percent reliability 1/

Item	Explanation	Conventional Till	Reduced Till	No-Till
		-------------1985 dollars/acre-------------		
Receipts	2.50/bushel	$315	$307	6300
Yields (bushels) — Conventional 126; Reduced 123; No-Till 120				
Variable Costs				
Seed (kernels)	24.200k @ .90/1000 kernels	22	22	22
Fertilizer				
N	140 lbs @ .20/lb	28	28	28
P_2O_5	44 lbs @ .22/lb	10	10	10
K_2O	60 lbs @ .11/lb	7	7	7
Lime	1000 lbs @ 15.00/ton	8	8	8
Chemicals	Conventional: Carbofuran - $12, Atrazine - $4, Metolachlor - $12; Reduced: Carbofuran - $12, Atrazine - $4, Metolachlor - $15, Isotox - $1; No-Till: Carbofuran - $12, Atrazine - $4, Metolachlor - $18, Isotox - $1, Paraquat - $8	28	32	43
Fuel, Oil & Grease		18	14	12
Drying - Fuel and Electric Only	.15/bu	18	18	18
Trucking - Fuel only		2	2	2
Repairs		18	16	14
Miscellaneous		12	12	12
Interest on Operating Capital		10	10	10
Total Variable Cost		181	179	186
Other Costs				
Labor Charge		15	12	9
Machine and Equipment Charge		50	50	50
Total Other Costs		65	62	59
Returns to Management and Land		69	66	55

1/ Pesticides used in crop production were restricted in order to meet Recommended Maximum Contamination Levels (RHCL) in drinking water as set by EPA, with a 50 percent reliability.

Source: Based on Ohio State University Extension Service enterprise budgets, Honey Creek watershed demonstration plot results and personal communications with EPA officials.

Table III-6. Ohio Extension Service continuous soybean production budgets, 1985. with pesticide use restrictions sufficient to meet Recommended Maximum Contamination Levels with a 50 percent reliability 1/

Item	Explanation	Conventional Till	Reduced Till	No-Till
		------------1985	dollars/acre	------------
Receipts	5.80/bushel	$250	$238	$250
Yield (bushels)				
Conventional 43 / Reduced 41 / No-Till 43				
Variable Costs				
Seed	1 bu. @ 13.00/bu	13	13	13
Fertilizer				
P_2O_5	40 lbs @ .22/lb	9	9	9
K_2O	55 lbs @ .11/lb	6	6	6
Lime	1000 lbs @ 15.00/Ton	8	8	8
Manganese	6 lbs @ .20/lb	1	1	1
Chemicals				
	Conventional: Metribuzin - $12, Metolachlor - $12; Reduced: Metribuzin - $12, Metolachlor - $12, Paraquat - $8, Metalaxyl - $3; No-Till: Metribuzin - $16, Metolachlor - $18, Paraquat - $8, Metalaxyl - $3	24	35	45
Fuel, Oil & Grease		18	14	12
Trucking - Fuel Only		1	1	1
Repairs		17	16	15
Miscellaneous		12	12	12
Interest on Operating Capital		7	8	8
Total Variable Cost		116	123	130
Other Costs				
Labor Charge		14	11	8
Machine and Equipment Charge		50	50	50
Total Other Costs		64	61	58
Returns to Management and Land		70	54	62

1/ Pesticides used in crop production were restricted in order to meet Recommended Maximum Contamination Levels (RMCL) in drinking water as set by EPA, with a 50 percent reliability.

Source: Eased on Ohio State University Extension Service enterprise budgets, Honey Creek watershed demonstration plot results and personal communications with EPA officials.

Table III-7. Ohio Extension Service production budgets for corn and soybean rotations, 1985, with pesticide use restrictions sufficient to meet Recommended Maximum Contamination Levels with a 50 percent reliability 1/

Item	Conventional Till	Reduced Till	No-Till
	----------1985 dollars/acre----------		
Receipts 2/	283	257	275
Total Variable Cost 3/	140	142	150
Total Other Costs 4/	65	62	59
Returns to Management and Land	78	71	66

1/ Pesticides used in crop production were restricted in order to meet Recommended Maximum Contamination Levels (RMCL) in drinking water as set by EPA, with a 50 percent reliability.

2/ Based on the following yields and prices (discrepancies due to rounding):

	Price $/bushel	Conventional till	Reduced till	No-till
		------ bushels/acre for two year rotation-----		
Corn	2.50	126	123	118
Soybeans	5.80	43	42	44

3/ Variable costs per acre are the average costs associated with continuous corn and soybeans (Tables IV-5 and IV-6) with the following adjustments

- Corn in rotation requires $4 per acre less nitrogen and $12 per acre less chemicals (Carbofuran) than continuous corn

4/ Average of other costs incurred under continuous corn and soybeans under corresponding tillage practices.

Source: Based on Ohio State University Extension Service enterprise budgets, Honey Creek watershed demonstration plot results and personal communications with EPA officials.

for all crops and a slight decrease in average yields on acreage planted to continuous corn.

As a final step undertaken to illustrate the potential threat to drinking water from pesticide contamination, pesticide use restrictions were made even more limiting. Pesticide use restrictions were such that under computer simulations of surface and ground water hydrology, RMCLs, as set by EPA, were met with a 95 percent reliability. The only pesticide changes required under this restriction are fonofos substituted for carbofuran on conventionally tilled corn and trifluralin for metolachlor on conventionally tilled soybeans. These substitutions resulted in modest increases in chemical costs, but significant changes in crop yields are not expected. Expected receipts and costs with this pesticide restriction are presented in Tables III-8 through III-10.

C. Yield variations by land class

As previously discussed, cropland soils in the Honey Creek watershed have been classified into four productivity groups based on the adaptability of the soils to conservation tillage practices. Class I soils are defined as always suitable for row crops under all tillage practices; receipts and returns depicted in Tables III-1 through III-10 apply to this land classification. Receipts and returns are somewhat lower for conservation-till crops grown on other land classes because of lower yields. Expected yield reduction for the various tillage-land classification combinations are summarized in Table III-11 for corn and soybeans. Hay yields are not expected to vary significantly among land classifications.

2. Phosphorus Loss Estimates

Agricultural nonpoint sources deliver highly stochastic and diverse loads and concentrations of phosphorus to receiving waters. Consequently the reliability of nonpoint phosphorus controls -- in this case, conservation tillage -- in meeting load reduction objectives must be considered. The

Table III-8. Ohio Extension Service continuous corn production budgets, 1985, with pesticide use restrictions sufficient to meet Recommended Maximum Contamination Levels with a 95 percent reliability 1/

Item	Explanation			Conventional Till	Reduced Till	No-Till
				-------------1985 dollars/acre------------		
Receipts		2.50/bushel		$315	$307	$300
Yields (bushels)						
Conventional 126	Reduced 123	No-Till 120				
Variable Costs						
Seed (kernels)	24.200k @	.90/1000 kernels		22	22	22
Fertilizer						
N	140 lbs @	.20/lb		28	28	28
P_2O_5	44 lbs @	.22/lb		10	10	10
K_2O	60 lbs @	.11/lb		7	7	7
Lime	1000 lbs @	15.00/Ton		8	8	8
Chemicals						
Conventional	Reduced	No-Till				
Fonofos - $13 Atrazine - $4 Metolachlor - $12	Carbofuran - $12 Atrazine - $4 Metolachlor - $15 Isotox - $1	Carbofuran - $12 Atrazine - $4 Metolachlor - $18 Isotox - $1 Paraquat - $8		29	32	43
Fuel, Oil & Grease				18	14	12
Drying - Fuel and Electric Only .15/bu				18	18	18
Trucking - Fuel only				2	2	2
Repairs				18	16	14
Miscellaneous				12	12	12
Interest on Operating Capital				10	10	10
Total Variable Cost				182	179	186
Other Costs						
Labor Charge				15	12	9
Machine and Equipment Charge				50	50	50
Total Other Costs				65	62	59
Returns to Management and Land				68	66	55

1/ Pesticides used in crop production were restricted in order to meet Recommended Maximum Contamination Levels (RMCL) in drinking water as set by EPA, with a 95 percent reliability.

Source: Based on Ohio State University Extension Service enterprise budgets, Honey Creek watershed demonstration plot results and personal communications with EPA officials.

Table III-9. Ohio Extension Service continuous soybean production budgets. 1985, with pesticide use restrictions sufficient to meet Recommended Maximum Contamination Levels with a 95 percent reliability 1/

Item	Explanation			Conventional Till	Reduced Till	No-Till
				------------1985 dollars/acre------------		
Receipts			5.80/bushel	$250	$238	$250
Yield (bushels)						
Conventional	Reduced	No-Till				
43	41	43				
Variable Costs						
Seed	1 bu. @ 13.00/bu			13	13	13
Fertilizer						
P_2O_5	40 lbs @ .22/lb			9	9	9
K_2O	55 lbs @ .11/lb			6	6	6
Lime	1000 lbs @ 15.00/Ton			8	8	8
Manganese	6 lbs @ .20/lb			1	1	1
Chemicals						
Conventional	Reduced	No-Till		27	35	45
Metribuzin - $15 Trifluralin - $12	Metribuzin - $12 Metolachlor - $12 Paraquat - $8 Metalaxyl - $3	Metribuzin - $16 Metolachlor - $18 Paraquat - $8 Metalaxyl - $3				
Fuel, Oil & Grease				18	14	12
Trucking - Fuel Only				1	1	1
Repairs				17	16	15
Miscellaneous				12	12	12
Interest on Operating Capital				7	8	8
Total Variable Cost				119	123	130
Other Costs						
Labor Charge				14	11	8
Machine and Equipment Charge				50	50	50
Total Other Costs				64	61	58
Returns to Management and Land				67	54	62

1/ Pesticides used in crop production were restricted in order to meet Recommended Maximum Contamination Levels (RMCL) in drinking water as set by EPA, with a 95 percent reliability.

Source: Based on Ohio State University Extension Service enterprise budgets, Honey Creek watershed demonstration plot results and personal communications with EPA officials.

Table III-10. Ohio Extension Service production budgets for corn and soybean rotations, 1985, with pesticide use restrictions sufficient to meet Recommended Maximum Contamination Levels with a 95 percent reliability 1/.

Item	Conventional Till	Reduced Till	No-Till
	------------1985 dollars/acre------------		
Receipts 2/	280	275	275
Total Variable 3/	142	142	150
Total Other Costs 4/	65	62	59
Returns to Management and Land	73	71	66

1/ Pesticides used in crop production were restricted in order to meet Recommended Maximum Contamination Levels (RMCL) in drinking water as set by EPA, with a 95 percent reliability.

2/ Based on the following yields and prices (discrepancies due to rounding):

	Price	Conventional till	Reduced till	No-till
	$/bushel	------bushels/acre for two year rotation-----		
Corn	2.50	126	123	118
Soybeans	5.80	42	42	44

3/ Variable costs per acre are the average costs associated with continuous corn and soybeans (Tables IV-8 and IV-9) with the following adjustments:

- Corn in rotation requires $4 per acre less nitrogen and the application of fonofos and carbofuran is eliminated.

4/ Average of other costs incurred under continuous corn and soybeans under corresponding tillage practices.

Source: Based on Ohio State University Extension Service enterprise budgets, Honey Creek watershed demonstration plot results and personal communications with EPA officials.

Table III-11. Estimated reductions in crop yields by soil classification and crop tillage practice

Soil classification	Total acreage in watershed	Corn: Conventional till	Corn: Reduced till	Corn: No-till	Soybean: Conventional till	Soybean: Reduced till	Soybean: No-till
		percent reduction in yield 1/					
I. Always suitable for conservation till	5,369	0	0	0	0	0	0
II. Suitable for conservation till if late-planted	23,285	0	0	0	0	0	0
III. Suitable for conservation till if drained	22,000	0	5	10	0	0	5
IV. Not suitable for conservation till	7,704	0	10	15	0	5	10

1/ Actual yields are presented in Tables III-1. III-2, III-5, III-6, III-8 and III-9 for each practice and pesticide restriction level.

Source: Based on Honey Creek watershed demonstration plot yields and information supplied by Ohio Extension specialists and EPA officials.

probabilistic methodology used to derive the phosphorus loss estimates provides a more realistic basis for appraisal of control costs for nonpoint sources. Furthermore, this methodology provides a consistent framework for cost comparisons between nonpoint phosphorus controls (e.g., conservation tillage) and point source control technologies (e.g., POTWs).

Phosphorus loads for the basin were estimated by EPA analysts (Milon, undated) using the runoff, erosion and recharge parameters from the 29-year simulation of the Pesticide Root Zone Model (PRZM) (Carsel et al., 1984) and the storm event loading functions for surface and ground water loads (Haith and Tubbs, 1981). The effects of conservation tillage on soil nutrient concentrations were determined using the enrichment ratio approach described by Baker and Laflen (1983). Edge-of-stream phosphorus loadings were determined based on prior simulations of sediment and runoff processes in the basin using the Hydrological Simulation Program - FORTRAN (HSPF) (Johanson et al., 1984). No attempt was made to estimate in-stream phosphorus concentrations. Annual exceedance probabilities for nutrient loads were determined from the 29-year precipitation record. Alternative reliability requirements for phosphorus control were estimated by EPA analysts exploiting the phosphorus exceedance probability function as a constraint in the programing model.

Table III-12 presents edge-of-stream phosphorus loadings from cropland devoted to corn, soybeans and hay under different tillage practices and phosphorus control reliability levels (thresholds). As shown, phosphorus loadings are reduced considerably by changing from conventional, till to reduced till; incremental load reductions resulting from the change from reduced till to no-till are relatively more modest.

Because nonpoint sources deliver highly variable loads to receiving waters, phosphorus loading estimates are presented for different levels of control reliability -- specifically 50, 60, 75 and 95 percent reliability. Interpretation of these reliability levels is straightforward; simply

Table III-12. Honey Creek watershed edge-of-stream phosphorus loadings for corn, soybeans and hay under different tillage practices

Phosphorus control reliability level 1/	Corn			Soybeans			Hay
	Conventional till	Reduced till	No-till	Conventional till	Reduced till	No-till	
	pounds/acre						
50	2.00	0.52	0.46	1.88	0.86	0.63	0.30
60	2.19	0.59	0.51	2.06	1.01	0.75	0.35
75	2.52	0.73	0.62	2.42	1.20	0.92	0.46
95	3.26	1.04	0.65	3.20	1.69	1.33	0.69

1/ Actual edge-of-stream phosphorus loadings will be at or below estimated level with the designated percent reliability. For example, with conventional till corn, edge-of-stream phosphorus loadings will be at or below 2.00 pounds per crop acre with 50 percent reliability.

Source: Estimates provided by EPA.

stated, phosphorus loadings will be at or below the specified target levels with the designated percent reliability.

D. Cost-effectiveness Estimates

The resulting cost-effectiveness estimates presented in this section for the Honey Creek watershed are based on critical assumptions regarding baseline cropping and tillage practices. For purposes of this case study, the prevailing cropping and tillage practices during the period when the Honey Creek land use surveys were conducted (1979-1982) is defined as the baseline (Milon, undated). Under this definition, approximately 25 percent of the row crop acreage is in continuous corn, 15 percent in continuous soybeans and the remaining 60 percent is in a corn and soybean rotation. All acreage is managed with conventional tillage practices. Total edge-of-stream phosphorus loadings from the 58,358 acres of crops in the watershed are estimated to be 113,565 pounds under baseline cropping and tillage practices.

While the baseline definition is representative of land use in the watershed, it does not represent the profit maximizing solution as per the LP model. Profit maximization would be achieved with all of the acreage in a corn and soybean rotation; corn and soybeans planted in rotation are slightly more profitable than continuously planted crops due to reduction in pesticide and fertilizer requirements. Estimates presented in this section were made under the baseline definition of cropping practices reflective of conditions prevailing in the watershed when the land use inventory was completed in 1979.

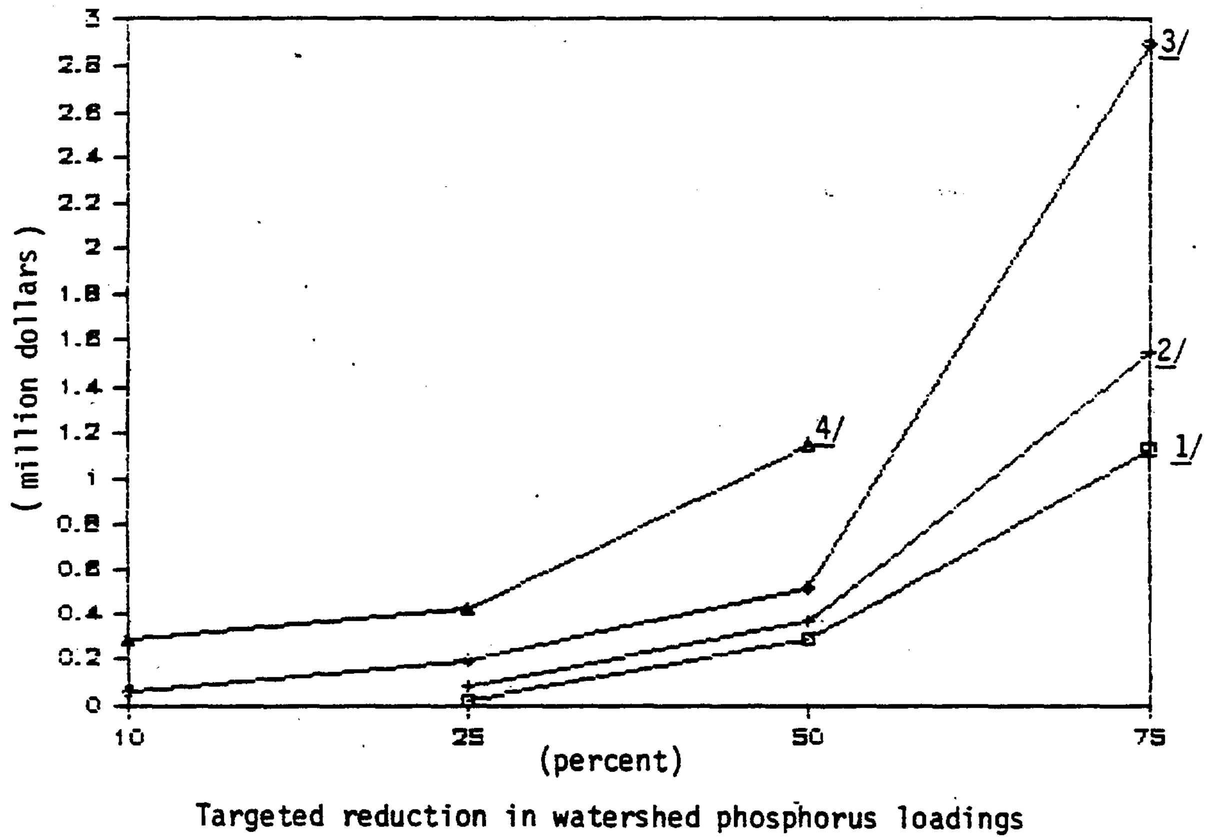
Implementation of conservation tillage practices leads to lower phosphorus loadings as well as other beneficial results, such as reductions in sediment losses and other nutrients which are not considered here. Costs of implementation are attributable to phosphorus only (although some of the estimates are made subject to pesticide use restrictions).

As discussed previously, the cost-effectiveness of conservation tillage in reducing phosphorus loadings is dependent on both the targeted phosphorus load reduction and the desired reliability of actually achieving targeted reduction levels in any given year. In this section, results are presented for targeted watershed reductions of 10, 25, 50 and 75 percent. Reliability thresholds considered for achieving these reductions in any given year are 56, 60, 75 and 95 percent. A graphical analysis of aggregate watershed reductions in economic returns for each targeted phosphorus reduction level and reliability threshold is presented in Figure III-2. The cost-effectiveness of conservation tillage in reducing phosphorus loadings for each targeted phosphorus reduction level and reliability threshold is presented graphically in Figure III-3. In both figures, no pesticide use restrictions are in effect. As indicated in the figures, costs for reducing phosphorus loadings increase as the reliability of achieving the targeted reductions increases.

Estimates of the cost-effectiveness of conservation tillage in achieving targeted reductions (with 50 percent reliability) in edge-of-stream phosphorus loadings are presented in Table III-13. As targeted reductions in phosphorus loadings are increased from 10 to 50 percent in the watershed, an increasing percentage of the acreage comes under reduced till. Crops under each targeted phosphorus reduction level are continuous corn and the corn-soybean rotation; continuous soybeans do not enter the optimized solution because of relatively high phosphorus loadings. In order to achieve the largest targeted phosphorus reduction examined (75 percent), 15 percent of the acreage must be put in hay. Hay enters the optimal solution on acreages not suitable for conservation till (Class IV land) and lands suitable for conservation till only when drained (Class III land).

Cost estimates for targeted reductions in phosphorus loadings of 10 percent are negative, reflecting more profitable crop rotations than initially practiced in the watershed. Targeted reductions in phosphorus loadings of 25 percent are estimated to cost $0.71 per pound, whereas targeted

Figure III-2. Honey Creek watershed declines in return to management and land from reducing edge-of-stream phosphorus loadings via conservation tillage



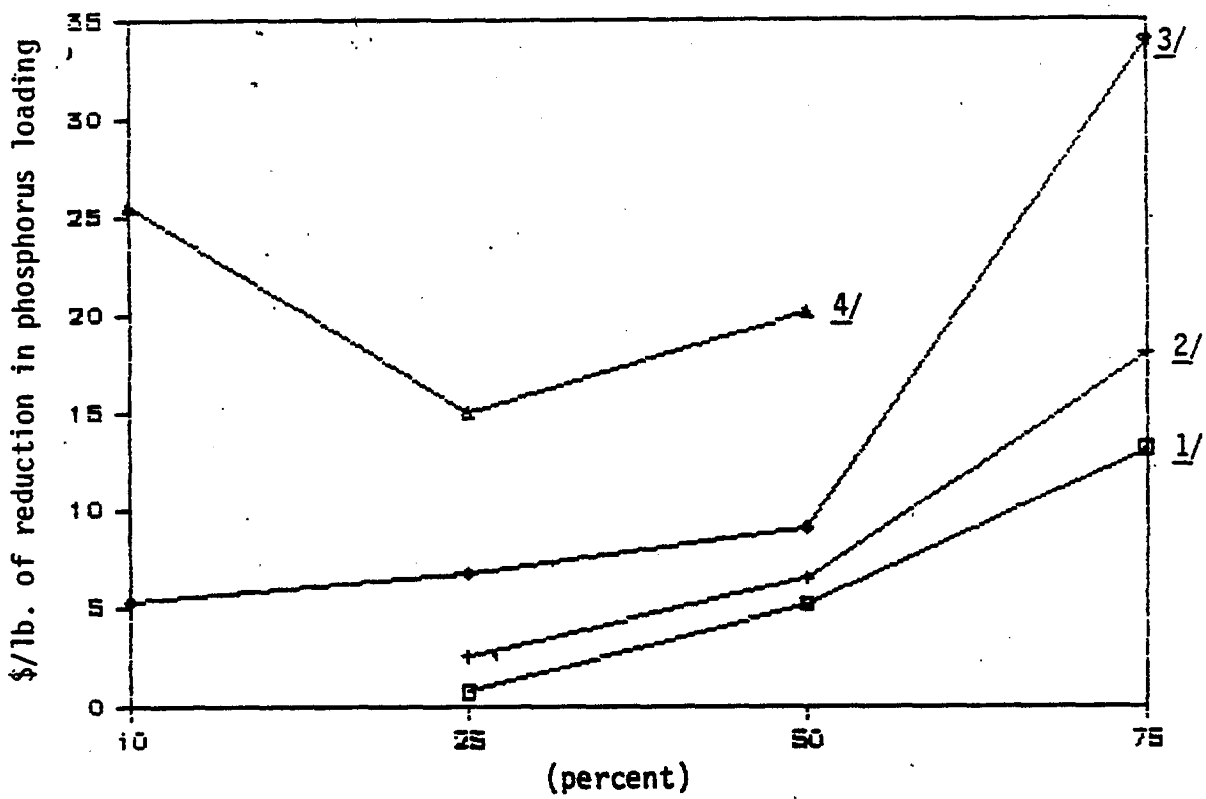
1/ Reliability threshold for achieving targeted reduction in any year is 50 percent.

2/ Reliability threshold for achieving targeted reduction in any year is 60 percent.

3/ Reliability threshold for achieving targeted reduction in any year is 75 percent.

4/ Reliability threshold for achieving targeted reduction in any year is 95 percent.

Figure III-3. Cost-effectiveness of conservation tillage in achieving targeted reductions in edge-of-stream phosphorus loadings in Honey Creek watershed



Targeted reductions in watershed phosphorus loadings

1/ Reliability threshold for achieving targeted reduction in any year is 50 percent.

2/ Reliability threshold for achieving targeted reduction in any year is 60 percent.

3/ Reliability threshold for achieving targeted reduction in any year is 75 percent.

4/ Reliability threshold for achieving targeted reduction in any year is 95 percent.

Table III-13. Cost-effectiveness of conservation tillage in achieving targeted reductions in edge-of-stream phosphorus loadings in the Honey Creek watershed with a 50 percent reliability 1/

Targeted reductions in phosphorus loadings 1/ (total watershed)	Total watershed returns to management and land	Crop mix: % of acres	Crop mix: Tillage method 2/	Average cost-effectiveness
-------(percent)------	---(thousand dollars)---			(dollars/lb.)
Baseline 3/	4,511.1	Continuous corn		-
		25	C	
		Continuous soybeans		
		15	C	
		Corn & soybean rotation		
		60	C	
10	4,598.9	Continuous corn		4/
		13	R	
		Corn & soybean rotation		
		87	C	
25	4,490.9	Continuous corn		0.71
		34	R	
		Corn & soybean rotation		
		66	C	
50	4,221.8	Continuous corn		5.10
		49	R	
		Corn & soybean rotation		
		29	C	
		22	R	
75	3,386.8	Continuous corn		13.20
		85	R	
		Hay		
		15	-	

1/ Expected edge-of-stream phosphorus loading reductions will be at or below targeted values with a 50 percent reliability.

2/ Tillage method code: C - conventional till
R - reduced till
N - no-till

3/ Represents total phosphorus loss estimate under cropping and tillage practices during the period when the Honey Creek land use surveys were conducted. Baseline edge-of-stream phosphorus losses are estimated to be 113,565 pounds from 58,358 acres.

4/ Cost-effectiveness measure is negative reflecting more profitable tillage practices and crop rotations than initially practiced in the watershed.

reductions of 50 and 75 percent are estimated to cost $5.10 and $13.20 per pound of phosphorus, respectively. The reliability (probability) of achieving these reductions in any year is 50 percent.

Cost-effectiveness estimates of conservation tillage practices presented in Tables III-14 through III-16 represent continually higher levels of reliability in meeting targeted phosphorus load reductions; reliability thresholds for achieving targeted reductions are 60, 75 and 95 percent. As in Table III-13, no pesticide restrictions are imposed in these analyses.

In Table III-16, cost-effectiveness estimates of achieving targeted reductions of phosphorus loadings from Honey Creek watershed are presented; the reliability of achieving targeted reductions in this analysis is 95 percent. Reductions in returns to management and land for the watershed are just over $290,000 for a 10 percent reduction in phosphorus loadings -- an average cost of nearly $26 per pound of phosphorus. Reductions in returns to management and land are over $427,000 for a 25 percent reduction in phosphorus loadings -- an average cost of $15 per pound of phosphorus. The lower average cost for phosphorus reductions as the targeted phosphorus loss reduction increases from 10 to 25 percent is due to the relatively modest decrease in returns from changing tillage practices on acreages in corn-soybean rotations. This change in tillage practice reduces returns by only $15 per acre on Class III land, while reducing phosphorus loadings by 1.86 pounds per acre. Reductions in returns are $1,142,000 for a 50 percent reduction in phosphorus loadings -- an average cost of over $20 per pound of phosphorus. Targeted reductions in phosphorus loadings of 75 percent are not feasible. It is not possible -- with 95 percent reliability -- to achieve targeted phosphorus loading reductions of 75 percent in the watershed.

With the pesticide use restrictions sufficient to meet Recommended Maximum Contamination Levels (RMCLs) in drinking water, costs for reducing, phosphorus loadings increase -- in some cases dramatically. Table III-17 depicts changes in watershed returns to management and land and

Table III-14. Cost-effectiveness of conservation tillage in achieving targeted reductions in edge-of-stream phosphorus loadings in the Honey Creek watershed with a 60 percent reliability 1/

Targeted reductions in phosphorus loadings 1/ (total watershed)	Total watershed returns to management and land	Crop mix: crop	Crop mix: % of acres	Crop mix: Tillage method 2/	Average cost-effectiveness
-------(percent)------	---(thousand dollars)---				(dollars/lb.)
Baseline 3/	4,511.1	Continuous corn	25	C	-
		Continuous soybeans	15	C	
		Corn & soybean rotation	60	C	
10	4,537.0	Continuous corn	25	R	4/
		Corn & soybean rotation	75	C	
25	4,438.1	Continuous corn	44	R	2.57
		Corn & soybean rotation	56	C	
50	4,145.6	Continuous corn	49	R	6.44
		Corn & soybean rotation	21	C	
			30	R	
75	2,968.9	Continuous corn	64	R	18.11
		Hay	36	-	

1/ Expected edge-of-stream phosphorus loading reductions will be at or below targeted values with a 60 percent reliability.

2/ Tillage method code: C - conventional till
R - reduced till
N - no-till

3/ Represents total phosphorus loss estimate under cropping and tillage practices during the period when the Honey Creek land use surveys were conducted. Baseline edge-of-stream phosphorus losses are estimated to be 113,565 pounds from 58,358 acres.

4/ Cost-effectiveness measure is negative reflecting more profitable tillage practices and crop rotations than initially practiced in the watershed.

Table III-15. Cost-effectiveness of conservation tillage in achieving targeted reductions in edge-of-stream phosphorus loadings in the Honey Creek watershed with a 75 percent reliability 1/

Targeted reductions in phosphorus loadings 1/ (total watershed)	Total watershed returns to management and land	Crop mix: % of acres	Crop mix: Tillage method 2/	Average cost-effectiveness
-------(percent)-------	---(thousand dollars)---			(dollars/lb.)
Baseline 3/	4,511.1	Continuous corn		-
		25	C	
		Continuous soybeans		
		15	C	
		Corn & soybean rotation		
		60	C	
10	4,451.7	Continuous corn		5.23
		41	R	
		Corn & soybean rotation		
		59	C	
25	4,319.6	Continuous corn		6.75
		49	R	
		Corn & soybean rotation		
		41	C	
		10	R	
50	3,993.7	Continuous corn		9.11
		49	R	
		Corn & soybean rotation		
		8	C	
		43	R	
75	1,612.1	Continuous corn		34.04
		17	N	
		Hay		
		83	-	

1/ Expected edge-of-stream phosphorus loading reductions will be at or below targeted values with a 75 percent reliability.

2/ Tillage method code: C - conventional till
R - reduced till
N - no-till

3/ Represents total phosphorus loss estimate under cropping and tillage practices during the period when the Honey Creek land use surveys were conducted. Baseline edge-of-stream phosphorus losses are estimated to be 113,565 pounds from 58,358 acres.

Table III-16. Cost-effectiveness of conservation tillage in achieving targeted reductions in edge-of-stream phosphorus loadings in the Honey Creek watershed with a 95 percent reliability 1/

Targeted reductions in phosphorus loadings 1/ (total watershed)	Total watershed returns to management and land	Crop mix: % of acres	Crop mix: Tillage method 2/	Average cost-effectiveness
-------(percent)------	---(thousand dollars)---			(dollars/lb.)
Baseline 3/	4,511.1	Continuous corn		-
		25	C	
		Continuous soybeans		
		15	C	
		Corn & soybean rotation		
		60	C	
10	4,221.0	Continuous corn		25.54
		49	R	
		Corn & soybean rotation		
		29	C	
		22	R	
25	4,083.6	Continuous corn		15.06
		49	R	
		Corn & soybean rotation		
		14	C	
		37	R	
50	3,368.8	Continuous corn		20.12
		65	R	
		Corn & soybean rotation		
		35	N	
75	Infeasible solution 4/			

1/ Expected edge-of-stream phosphorus loading reductions will be at or below targeted values with a 95 percent reliability.

2/ Tillage method code: C - conventional till
R - reduced till
N - no-till

3/ Represents total phosphorus loss estimate under cropping and tillage practices during the period when the Honey Creek land use surveys were conducted. Baseline edge-of-stream phosphorus losses are estimated to be 113,565 pounds from 58,358 acres.

4/ Targeted phosphorus reduction level cannot be achieved via conservation tillage practices by growing hay.

Table III-17. Cost-effectiveness of conservation tillage in achieving targeted reductions in edge-of-stream phosphorus loadings in the Honey Creek watershed with a 50 percent reliability and pesticide use restrictions sufficient to meet Recommended Maximum Contamination Levels with a 50 percent reliability 1/

Targeted reductions in phosphorus loadings 2/ (total watershed)	Total watershed returns to management and land	Crop mix			Average cost-effectiveness
		Crop	% of acres	Tillage method 3/	
--------(percent)------	---(thousand dollars)---				(dollars/lb.)
Baseline 4/	4,511.1	Continuous corn	25	C	-
		Continuous corn	15	C	
		Corn & soybean rotation	60	C	
10	4,490.3	Corn & soybean rotation	85	C	1.83
			15	R	
25	4,394.9	Corn & soybean rotation	62	C	4.09
			38	R	
50	4,104.0	Corn & soybean rotation	23	C	7.17
			77	R	
75	3,139.5	Continuous corn	85	R	16.10
		Hay	15	-	

1/ Pesticides used in crop production simulations were restricted in order to meet Recommended Maximum Contamination Levels (RMCL) in drinking water as established by EPA, with a 50 percent reliability.

2/ Expected edge-of-stream phosphorus loading reductions will be at or below targeted values with a 50 percent reliability.

3/ Tillage method code: C - conventional till
R - reduced till
N - no-till

4/ Represents total phosphorus loss estimate under cropping and tillage practices during the period when the Honey Creek land use surveys were conducted. Baseline edge-of-stream phosphorus losses are estimated to be 113,565 pounds from 58,358 acres.

cost-effectiveness estimates for phosphorus load reductions; in this analysis, targeted phosphorus load reductions and RMCLs are both expected to be met with 50 percent reliability. Costs per pound of phosphorus load reductions range from nearly $2 to over $16 for targeted watershed phosphorus load reductions ranging from 10 to 75 percent, respectively. This compares to a cost range of $0 to over $13 per pound of phosphorus without pesticide use restrictions (Table III-13).

Average cost-effectiveness estimates presented in Table III-18 are under conditions sufficient to achieve targeted phosphorus load reductions with 50 percent reliability and RMCLs with 95 percent reliability. The increase in reliability for achieving the RMCLs results in much higher cost-effectiveness estimates, primarily because of decreases in returns from acreages under conventionally tilled corn/soybean rotations. However, because the effects of the pesticide use restrictions are insignificant for crops grown under conservation tillage, average cost-effectiveness estimates for targeted watershed phosphorus loss reductions above 50 percent are only slightly higher than when pesticide use restrictions are not in effect.

Average cost-effectiveness estimates presented in Table III-19 are under conditions sufficient to achieve targeted phosphorus load reductions and RMCLs with 95 percent reliability. Cost-effectiveness estimates under these restrictions range from $22 to $43 per pound of phosphorus.

Table III-18. Cost-effectiveness of conservation tillage in achieving targeted reductions in edge-of-stream phosphorus loadings in the Honey Creek watershed with a 50 percent reliability and pesticide use restrictions sufficient to meet recommended Maximum Contamination Levels with a 95 percent reliability 1/

Targeted reductions in phosphorus loadings 2/ (total watershed)	Total watershed returns to management and land	Crop mix: % of acres	Crop mix: Tillage method 3/	Average cost-effectiveness
-------(percent)------	---(thousand dollars)---			(dollars/lb.)
Baseline 4/	4,511.1	Continuous corn		-
		25	C	
		Continuous soybeans		
		15	C	
		Corn & soybean rotation		
		60	C	
10	4,242.5	Corn & soybean rotation		23.65
		85	C	
		15	R	
25	4,215.3	Corn & soybean rotation		10.42
		62	C	
		38	R	
50	4,037.9	Corn & soybean rotation		8.33
		23	C	
		77	R	
75	3,139.5	Continuous corn		16.10
		85	R	
		Hay		
		15	-	

1/ Pesticides used in crop production simulations were restricted in order to meet Recommended Maximum Contamination Levels (RMCL) in drinking water as established by EPA, with a 95 percent reliability.

2/ Expected edge-of-stream phosphorus loading reductions will be at or below targeted values with a 50 percent reliability.

3/ Tillage method code: C - conventional till
R - reduced till
N - no-till

4/ Represents total phosphorus loss under cropping and tillage practices during the period when Honey Creek plot tests were conducted. Baseline edge-of-stream phosphorus losses are estimated to be 113,565 pounds from 58,358 acres.

Table III-19. Cost-effectiveness of conservation tillage in achieving targeted reductions in edge-of-stream phosphorus loadings in the Honey Creek watershed with 95 percent reliability and pesticide use restrictions sufficient to meet Recommended Maximum Contamination Levels with a 95 percent reliability 1/

Targeted reductions in phosphorus loadings 2/ (total watershed)	Total watershed returns to management and land	Crop mix: % of acres	Crop mix: Tillage method 3/	Average cost-effectiveness
-------(percent)------	---(thousand dollars)---			(dollars/lb.)
Baseline 4/	4,511.1	Continuous corn		-
		25	C	
		Continuous soybeans		
		15	C	
		Corn & soybean rotation		
		60	C	
10	4,025.5	Corn & soybean rotation		42.76
		21	C	
		79	R	
25	3,884.9	Corn & soybean rotation		22.06
		5	C	
		95	R	
50	3,104.7	Continuous corn		24.77
		76	R	
		24	N	
75	Infeasible solution 5/			

1/ Pesticides used in crop production simulations were restricted in order to meet Recommended Maximum Contamination Levels (RMCL) in drinking water as established by EPA, with a 95 percent reliability.

2/ Expected edge-of-stream phosphorus loading reductions will be at or below targeted values with a 95 percent reliability.

3/ Tillage method code: C - conventional till
R - reduced till
N - no-till

4/ Represents total phosphorus loss under cropping and tillage practices during the period when Honey Creek plot tests were conducted. Baseline edge-of-stream phosphorus losses are estimated to be 113,565 pounds from 58,358 acres.

5/ Targeted phosphorus reduction level cannot be achieved via conservation tillage practices or by growing hay.

IV. COST-EFFECTIVENESS OF POTWS CONTROLLING PHOSPHORUS

This chapter estimates the cost-effectiveness of POTWs in Region V in controlling phosphorus. The task was to identify POTWs in Region V with recently upgraded facilities for phosphorus removal and to develop cost-effectiveness estimates for this treatment. The information collected in the process of identifying facilities controlling phosphorus is presented in the first section of this chapter. Using the available information, a methodology was developed to estimate the cost-effectiveness of phosphorus removal, which is discussed in the second section. The results of the cost-effectiveness analysis are then presented in the final section of the chapter.

A. Identification of POTWs

Two sources were used to identify the POTWs with upgraded facilities for phosphorus removal; the EPA "Needs Survey" data base (EPA, 1985a) and Region V's "Construction Grants Information and Central System for Advanced Treatment Projects" (EPA, 1985). The Needs Survey data base includes plant location and incremental removals of BOD, TSS, phosphorus and ammonia. The Region V data includes plant location, permit number, reason for grant, treatment processes, capital cost for the treatment (advanced secondary or tertiary) and project status. Other information such as cost for new collection systems were included in the Region V data but were not used in this analysis. Both sources included plants where the upgrades were only in the planning or construction phases of completion.

Table IV-1 presents the number of POTWs in Region V which were identified from the two sources as POTWs with planned or recently upgraded facilities for phosphorus removal. The Needs Survey lists 208 POTWs with planned upgrades for phosphorus removal and the Region V list reports only 24 POTWs.

Table IV-1. Identification of facilities in Region V planned or recently upgraded for phosphorus removal

State	Needs Survey 1/	Region V 2/
	---------------Number of POTWs-------------	
Illinois	15	1
Indiana	22	3
Michigan	47	4
Minnesota	34	11
Ohio	86	7
Wisconsin	4	0
Total	208	26

1/ "Needs Survey" data base, September 1985, U.S. Environmental Protection Agency, Washington, D.C.

2/ "Construction Grants Information and Control System for Advanced Treatment Projects", August 1985, U.S. Environmental Protection Agency, Region V, Chicago, IL.

The state with the most upgraded POTWs identified in the Needs Survey data base was Ohio with 86 such POTWs. The Region V data base listed only seven upgraded POTWs in Ohio. Wisconsin had the fewest POTWs to be upgraded with four facilities identified in the Needs Survey and no facilities listed in the Region V data base. Only eleven POTWs in the Region V states were identified by both sources.

The large difference in the number of POTWs identified is due to the different definitions used in the data bases. The Needs Survey lists all facilities removing phosphorus, both specifically and incidentally, during removal of other pollutants. The Region V list reports facilities specifically planned or upgraded for phosphorus control.

In addition to information on POTWs upgrading for phosphorus removal, the Region V data base includes other construction grant requirements. For example, the most common reasons for the grants listed by Region V (in descending order) were to (1) increase capacity and treatment level, (2) construct a new wastewater treatment system, (3) increase capacity, and (4) increase treatment levels. The most common treatment processes used for upgrading POTWs in Region V are listed below. POTW upgrades include the following treatment processes:

- activated sludge
- lagoons and ponds
- filtration
- trickling filter
- chemical addition
- oxidation ditch
- bio discharge
- break point chlorination
- nitrification

As presented in Table IV-2, the EPA Region V data base reports a total of 277 facilities with upgrades planned or recently completed for any pollutants. The total capital cost for these facilities is $988 million.

Table IV-2. Number of POTW in Region V with planned or completed upgrades and associated capital costs 1/

State	Number of POTW upgrades	Total cost of upgrades	Number of POTW upgrades for phosphorus removal	Total cost for POTWs with phosphorus removal
		($)		($)
Illinois	68	192,769,649	1	2,491,840
Indiana	57	167,923,990	3	1,479,611
Michigan	29	138,151,448	4	29,376,058
Minnesota	51	85,647,748	11	31,259,572
Ohio	60	295,459,496	7	64,688,548
Wisconsin	12	107,973,249	0	0
Total	277	987,925,580	26	129,295,629

1/ U.S. Environmental Protection Agency, Region V, Chicago, Illinois and telephone contacts.

The total capital cost for the 26 facilities with phosphorus removal is $129 million. Ohio has the highest cost with a total of $295 million for all POTW upgrades and $65 million for POTW upgrades with phosphorus removal. Minnesota shows the lowest total construction grant costs at $86 million for all POTW upgrades while Wisconsin shows the lowest cost for POTW upgrades with phosphorus removal at $0.

The capital costs reported in Table IV-2 for all facilities are aggregate, including costs for the entire upgrade, rather than for just phosphorus removal. Annual operating and maintenance costs were not available to correspond with the capital costs reported by Region V.

The information collected from the two data sources was too limited to develop cost-effectiveness estimates. A major discrepancy was the lack of current annual operation and maintenance costs. Another significant data restriction was that capital costs for phosphorus removal were not reported in either data base. Thus the use of the capital costs for POTW upgrades reported by Region V would overstate the phosphorus removal cost. Instead of using engineering formulas to estimate operating and maintenance costs and capital costs for removal of phosphorus, actual costs for each facility were collected. Facility size, capital costs for removal of phosphorus, and phosphorus removal volumes were also compared to the Region V data.

Ten facilities from the Needs Survey data base, were contacted to determine the utility of the information. Of these ten POTWs, only two had been or were being built or upgraded for removal of phosphorus. Since this response was low, the 26 facilities identified in the Region V data base as specifically upgrading for phosphorus removal were also contacted individually to collect additional cost data.

Table IV-3 summarizes capital costs, facility size and phosphorus removal for each of the 26 facilities. The capital cost presented is from the Region V data base. Size of the facilities range from 0.1 million gallons per day to 100 million gallons per day (MGD). Phosphorus influent ranges from 2 to 15 milligrams per liter (mg/l). Phosphorus effluent ranges from 0.1 to 4 mg/l.

Table IV-3 Summary of capital cost, size and phosphorus influent and effluent for 26 POTWs in Region V 1/

Location	Capital cost (1985)	Size in MGD	Phosphorus level Influent mg/l	Phosphorus level Effluent mg/l
Shelbyville, IL	2,491,840	0.6	15.0	1.0
ILLINOIS	2,491,840			
Hamilton, IN	686,880	0.1	8.0	1.0
Sheridan, IN	198,450	0.1	10.0	1.0
Tipton, IN	594,281	1.2	3.0	0.4
INDIANA	1,479,611			
Grand Haven, MI	11,435,564	5.0	NA	NA
Ionia, MI	461,294	1.6	3.6	0.9
Marshall, MI Calhoun County	4,207,200	NA	NA	NA
Owosso, MI	13,272,000	4.5	5.0-6.0	0.4-0.5
MICHIGAN	29,376,058			
Albany, MN	3,184,380	0.03	3.0	1.0
Albert Lea, MN	5,605,379	NA	NA	NA
Aurora, MN	442,769	0.4	2.8-4.0	0.8
Bemidji, MN	4,609,100	1.1	3.0-8.0	0.1
Chisholm, MN	339,800	NA	NA	NA
Eveleth and Leonidas, MN	340,146	0.7	3.0	0.7-0.8
Fergus Falls, MN	526,113	1.2	10.0-14.0	0.9
Gilbert, MN	364,400	0.4	2.0	0.8
Marble and Calumet, MN	70,985	0.2	10.0	1.0
Pine Island, MN	1,657,200	0.3	6.0-10.0	1.0
Rochester, MN	14,119,300	10.0	14.0	2.0-4.0
MINNESOTA	31,259,572			
Astabula, OH	3,300,000	4.5	4.0	1.0
Cleveland, OH	8,058,418	100.0	10.0	1.0
Columbus, OH	20,000,000	NA	NA	NA
Galion, OH	777,700	NA	15.0	1.0
Kent, OH	1,500,000	3.0	7.0	0.5-0.6
North Olmsted, OH	1,000,000	6.0	5.0-6.0	1.0
Painesville, OH	30,052,430	30.0	4.7	1.0
OHIO	64,688,548			
TOTAL	129,295,629			

1/ U.S. EPA Region V, "Needs Survey" data base (September 1985) and telephone contacts.
NA = Not available.
MGD = million gallons per day
Mg/l = milligrams per liter

Plant managers for six of the 26 POTWs reported that phosphorus was not specifically removed at these facilities. These facilities included: Grand Haven, MI; Marshall,, MI; Albert Lea, MN; Chisolm, MN; and Columbus, OH. Columbus reported a removal of 30 percent of phosphorus influent incidentally. The other reports shown as NA (not available) in Table IV-3 are due to nonresponse to telephone contacts. Additional information on plant type, size and phosphorus removal were, therefore not collected for these POTWs. Summaries of the information collected for each of the other twenty POTWs are presented below by state.

1. Illinois

The Shelbyville, Illinois plant was under construction in 1985. Capacity will be 0.6 MGD. Capital cost reported by the facility superintendent was $4.7 million versus $2.5 million reported in the Region V construction grants list. No other plants were listed for Illinois.

2. Indiana

The Region V data base identified three POTWs in Indiana upgraded for phosphorus removal. These were Hamilton, Sheridan and Tipton. The total construction cost for all three facilities was $1.5 million. The Hamilton POTW was completed in 1980 and began operation in 1981. It averages 90 percent phosphorus removal and processes approximately 0.1 million gallons per day. New equipment for the Sheridan facility was recently installed. Wastewater treated was also approximately 0.1 MGD at this plant. The Tipton plant treats 1.2 MGD and uses an activated sludge system for secondary treatment. Ferric chloride is added to remove phosphorus. Indiana currently has a phosphate ban which reduces the plants' phosphorus influent concentration.

3. Michigan

Ionia and Owosso were the two cities identified in Michigan with POTWs upgraded to remove phosphorus. Ionia uses rotary biological discs with aluminum sulfate and polymer addition to achieve 75 percent removal of phosphorus. The aluminum sulfate is added to a grit chamber and the polymer is added at the end of the grit chamber. The facility treats 1.6 MGD of wastewater. Owosso uses chemical treatment, clarification and filtration to reduce phosphorus by 92 percent and achieve an effluent of about 0.5 milligrams per liter. The plant treats 4.5 MGD of wastewater.

The Grand Haven, Michigan POTW which reported that phosphorus was not a primary reason for its upgrade, removes 80 to 90 percent of phosphorus while treating primarily for BOD and TSS. A phosphate ban in Michigan reduces the phosphorus influent concentration to plants in the state. About 90 of the 502 POTWs in the state treat for phosphorus. Most were upgraded between 1974 and 1977.

4. Minnesota

Of the eleven POTWs in Minnesota listed by Region V as removing phosphorus, two POTWs reported that phosphorus was not specifically treated. Brief descriptions of the nine remaining POTWs are presented below.

The Albany POTW, completed in 1986, was the smallest facility contacted with 0.03 MGD of wastewater treated. Alum is used for chemical addition at a cost of $3,666 per year.

The Aurora facility was upgraded in 1980 for phosphorus removal. The 0.4 MGD plant uses extended aeration with a tertiary filter to treat wastewater.

The Bemidji facility treats 1.1 MGD of wastewater. The plant's treatment process includes activated sludge with chemical addition for phosphorus removal. Chemicals used are aluminum sulfate and polymers. The plant, located at the source of the Mississippi River, has a stringent phosphorus limit of 0.3 mg/l. The plant currently achieves an average 0.1 mg/l.

The POTW treats 0.7 MGD. The POTW uses activated sludge with chemical addition of alum for treating phosphorus. Alum use is 22 gallons per day at 32 cents per gallon.

The Fergus Falls facility uses extended aeration and chemical addition of ferric chloride to treat phosphorus. The plant treats 1.2 MGD of wastewater. The plant has been in operation since 1985.

A new building and tank for the Gilbert POTW were completed in 1980. Extended aeration with tertiary filters is the wastewater treatment process used. The facility uses 4,000 gallons of aluminum sulfate to treat for phosphorus.

The Marble facility will treat 0.2 MGD. The facility is planned but not yet under construction.

The Pine Island facility is an activated sludge unit which uses pickle liquor as a substitute for chemical additives to remove phosphorus. The plant treats 0.3 MGD of wastewater. Sludge handling costs are approximately $1200 per year.

The ten MGD Rochester facility has an activated sludge secondary treatment process. A PhoStrip process has been added to remove phosphorus. Currently the plant is not meeting the 1 mg/l limit. The high influent of 14 mg/l due to treatment of dairy wastewaters is part of the problem in meeting the effluent limit.

5. Ohio

The Region V data base listed seven facilities in Ohio to be upgraded for phosphorus removal. The Ashtabula facility is a recent upgrade requiring new pumps and installation of an aeration tank for this 4.5 MGD facility. The City of Cleveland has four plants being upgraded which range in size from 35 to 140 MGD.

The Kent, Ohio POTW is an activated sludge system with alum addition to remove phosphorus. The North Olmsted POTW is under construction and includes a new flocculation building. The Painesville POTW was expanded in 1980 and currently treats 30 MGD of wastewater. A 90 percent removal rate for phosphorus is experienced at the Painesville plant.

6. Wisconsin

Region V listed no POTWs in the state of Wisconsin being upgraded for phosphorus removal.

B. Cost-Effectiveness Methodology

The information required to determine the cost-effectiveness for phosphorus removal by each facility includes:

- POTW size in million gallons per day;
- number of operating days or annual flow;
- influent and effluent, phosphorus concentrations;
- advanced treatment technology used for phosphorus removal; and
- capital and annual operation and maintenance costs for phosphorus removal.

A primary difficulty in estimating phosphorus removal costs is the cost allocation problem due to POTWs treating for pollutants in addition to phosphorus. Since the information available from the two identified data sources included only total capital costs for treating all pollutants, estimates for treating only phosphorus had to be made. The facility contacts, usually the plant operator or engineer, were asked to make this estimate. Specifically requested were equipment, labor, energy, supplies, and sludge handling and removal costs.

To develop the cost-effectiveness estimates presented in the next section, four mathematical steps had to be completed:

1. Annualized capital cost was computed by multiplying the capital cost reported by the capital recovery factor (CRF) which is based on a 20 year life (n) and a 10 percent interest rate (i). 1/. It is derived as follows:

$$CRF = \frac{i}{1-(1+i)^{-n}}$$

$$CRF = .1175$$

2. Annual capital cost + annual operation and maintenance cost = annual treatment cost (all costs are reported in 1985 dollars).

3. Total phosphorus removed is estimated by subtracting the effluent concentration in mg/l from the influent concentration in mg/l and converting the removal concentration into pounds of.phosphorus removed per year using the following formula:

   mg/l removed X 8.34 X MGD X 365 = pounds of phosphorus removed per year

4. Annual treatment cost divided by pounds of phosphorus removed equals cost-effectiveness of the phosphorus treatment system.

C. Results of Cost-Effectiveness Analysis

The results of the cost-effectiveness analysis of POTWs in Region V for removing phosphorus are presented in this section. Of the 20 POTWs

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1/ The 10 percent interest rate was chosen to compare results to a previous study of POTW phosphorus removal cost-effectiveness (IEc, 1985) which relied on engineering estimates to determine costs.

identified by Region V (the original 26 POTWs less the six deleted in the first telephone interviews), adequate information to conduct an analysis was collected on only 11 POTWs. All of these POTWs have completed construction of the upgrades necessary to remove phosphorus and are in operation. The data obtained from these POTWs were used in the development of the cost-effectiveness estimates; all data inputs were provided by the POTWs.

Case studies for each of the eleven POTWs were developed and are presented in Appendix B. The data inputs and cost-effectiveness estimates are summarized in Tables IV-4 and IV-5.

Chemical addition to precipitate phosphorus was the most common treatment used by the eleven POTWs. All but one facility used this treatment process. The chemicals used included aluminum sulfate, ferric chloride,. iron and polymers and steel mill waste pickle liquor.. Pickle liquor was a cheaper substitute for chemicals.

Rochester, Minnesota was the one facility using a different treatment process. Rochester uses a proprietary process called PhoStrip. This process is both a biological and chemical treatment process. Filters may have also been used in several cases, although this was not always confirmed through the data collection tasks.

As shown in Table IV-4 the POTWs ranged in size from 0.3 to 10 MGD. Capital costs for removal of phosphorus ranged from $20,000 to $3,500,000. Annual operation and maintenance costs ranged from $2,500 to $450,000.

Table IV-5 presents the phosphorus influent and effluent, total phosphorus removed, annual phosphorus treatment cost and cost-effectiveness for each of the POTWs. Phosphorus influent levels ranged from 2.0 to 14.0 mg/l; phosphorus effluent levels ranged from 0.1 to 1.0 mg/l. Total phosphorus removed ranged from 1,351 to 395,733 pounds per year.

Table IV-4. Actual capital and annual operation and maintenance costs for eleven POTWs in Region V

POTW Location	Size 1/	POTW Capital cost 2/	Capital cost P 3/	POTW O&M cost 4/	O&M cost to remove P 5/
	(MGD)	$	$	$	$
Pine Island, MN	0.3	1,700,000	352,000	1,657,200	7,722
Gilbert, MN	0.4	2,346,091	234,609	364,400	2,500
Aurora, MN	0.44	2,200,000	220,000	442,769	2,660
Eveleth, MN	0.7	5,000,000	20,000	340,146	3,520
Bemidji, MN	1.1	14,000,000	491,480	4,609,100	82,000
Fergus Falls MN	1.16	9,000,000	150,000	526,113.	60,225
Tipton, IN	1.17	6,088,100	250,000	594,281	9,000
Ionia, MI	1.6	7,073,078	235,455	461,294	33,500
Kent, OH	3.0	8,400,000	30,000	1,150,000	91,365
Owosso, MI	4.5	12,000,000	150,000	13,272,000	70,000 to 75,100
Rochester, MN	10.0	56,000,000	3,500,000	14,119,300	450,000

1/ POTW size in million gallons per day (MGD).
2/ Total capital cost for each POTW upgrade.
3/ Capital cost designated for phosphorus removal.
4/ Total annual operation and maintenance cost for POTW upgrade.
5/ Annual operation and maintenance cost for phosphorus removal.

Table IV-5. Treatment of phosphorus, annual treatment cost and estimated cost-effectiveness for eleven POTWs in Region V

POTW Location	Size 1/	Phosphorus Influent 2/	Phorphorus Effluent 3/	Total phosphorus removed 4/	Annual treatment cost 5/	Cost-effectiveness 6/
	MGD	(mg/l)	(mg/l)	(lb/yr)	($yr)	($/lb/yr)
Pine Island, MN	0.3	6.0-10.0	1.0	4,504- 8,106	49,082	$6.06 to $10.90
Gilbert, MN	0.4	2.0	0.8	1,461	30,067	$20.58
Aurora, MN	0.44	2.8- 4.0	0.8	2,702- 4,323	28,510	$6.60 to $10.56
Eveleth, MN	0.7	3.0	0.7-0.8	4,137- 4,326	5,870	$1.36 to $1.42
Bemidji, MN	1.1	3.0- 8.0	0.1	9,711- 26,453	139,749	$5.28 to $14.39
Fergus Falls, MN	1.16	10.0-14.0	0.9	44,170- 63,586	77,850	$1.22 to $1.76
Tipton, IN	1.17	3.0	0.44	8,092	38,375	$4.75
Ionia, MI	1.6	3.6	0.9	1,351	61,166	$4.65
Kent, OH	3.0	7.0	0.5-0.6	58,447- 59,360	94,890	$1.60 to $1.62
Owosso MI	4.5	5.0-6.0	0.4-0.5	61,643- 76,711	87,625 to 92,625	$1.14 to $1.50
Rochester, MN	10.0	14.0	1.0	395,733	861,250	$2.18

1/ POTW size in million gallons per day (MGD).
2/ Average or range of phosphorus influent.
3/ Average or range of phosphorus effluent.
4/ Average or range of total phosphorus removed.
5/ Average or range of annual treatment costs for phosphorus.
6/ Cost-effectiveness average or range estimated by dividing annual treatment cost by total phosphorus removed.

Annual treatment costs ranged from $5,870 to $861,250. Cost-effectiveness estimates ranged from $1.14 to $20.58 per pound of phosphorus removed.

The Rochester, Minnesota plant which is the only plant using the PhoStrip process for removing phosphorus, is currently not meeting the 1.0 mg/l effluent design criteria. The 14.0 mg/l influent for this plant is also higher than for the other facilities due to effluent from the dairy industry in the area. Actual effluent for the Rochester POTW ranges from 2.0 mg/l to 4.0 mg/l. The cost for correcting the operation to 1.0 mg/l is included in the analysis since the other facilities achieved or did better than the 1.0 mg/l effluent limit. The marginal cost for the Rochester plant to go from the actual effluent to 1.0 mg/l is $300,000. This converts to a marginal cost per pound of phosphorus ranging from $3.29 to $9.86 per pound.

Since similar treatment systems are used--chemical addition, likely augmented in some cases with filters--the POTWs were grouped by size to develop average cost-effectiveness values. Values for three sizes of facilities are presented below.

Size Range (MGD)	Number of Facilities	Average Size (MGD)	Cost-Effectiveness Range ($/lb)	Cost-Effectiveness Weighted Average ($/lb)
< 0.5	3	0.4	6.06 - 20.58	9.55
0.5 - 1.9	5	1.2	1.22 - 14.39	3.77
2.0 & UP	3	5.8	1.14 - 2.18	2.00

because the sample size of 11 POTWs may not accurately represent the cost-effectiveness of the overall POTW population, it is useful to compare these results with a similar study completed in the Great Lakes Basin by SAIC which focused on larger facilities. The results of the SAIC study (SAIC, 1988) are summarized in the following section for purposes of comparison.

D. Comparative Results of Similar Research

In this section, phosphorus removal cost-effectiveness estimates obtained through a study of the economic impacts of detergent phosphorus bans on Great Lakes basin municipal wastewater treatment plants are summarized. The study (SAIC, 1988) classified POTWs according to whether or not they were affected by phosphorus ban legislation and analyzed the variations in cost on that basis. For purposes of this presentation, all POTWs included in the study are analyzed as one group.

Table IV-6 summarizes the results of the analysis of 23 POTWs in the Great Lakes basin. The size of the POTWs range from 1.9 to 79.0 MGD of wastewater treated in 1982 and 1983. The cost-effectiveness of phosphorus removal ranges from $0.23 to $2.60 per pound. A summary of the cost-effectiveness of the facilities is presented below by general size category.

Size Range (MGD)	Number of Facilities	Average Size (MGD)	Cost-effectiveness Range ($/lb)	Cost-effectiveness Weighted Average ($/lb)
< 5.0	4	3.2	0.98 - 2.06	1.37
5.0 - 9.9	7	7.7	0.54 - 2.47	1.24
10.0 - 19.9	8	13.4	0.45 - 1.22	0.68
20.0 & UP	4	52.7	0.23 - 0.92	0.41

These averages are primarily for plants larger than those studied in the Previous section. There appear to be significant economies of scale for phosphorus removal (i.e., larger facilities, on average experience lower phosphorus removal costs on a per pound basis).

Table IV-6. Estimated cost-effectiveness of phosphorus removal for twenty-three POTWs in the Great Lakes basin

	Size 1/	Phosphorus Influent 2/	Phosphorus Effluent 2/	Phosphorus Removal Cost-effectiveness	Facilities affected by phosphorus ban
	(MGD)	(mg/l)	(mg/l)	(1985 $/lb)	
French Creek, OH	1.9	6.8	0.85	1.45	
Oregon, OH	3.2	4.4	0.90	2.06	
Painesville, OH	3.6	5.3	0.44	0.98	
De Pere, WI 3/	3.9	6.7	0.50	1.29	
Midland, MI	6.6	4.0	0.28	1.26	X
N. Tonawanda, NY 4/	6.9	2.4	0.62	2.47	X
Font Du Lac, WI 3/	7.5	8.3	0.64	1.35	
Maumee River, OH 3/	7.5	4.4	0.50	2.60	
Benton Harbor, MI	7.8	4.7	0.70	0.54	X
Willoughby, OH	8.0	6.2	0.85	0.98	
Manitowoc, WI 3/	9.9	7.2	0.74	0.80	
E. Lansing, MI	11.2	5.3	0.91	0.54	X
Oshkosh, WI 3/	11.2	4.0	0.41	0.77	
Monroe NWQ, NY	11.7	4.5	0.93	1.22	X
Sheboygan, WI 3/	11.8	4.7	0.95	0.45	
Monroe GCO, NY	12.5	4.8	0.89	0.99	X
Lima, OH	14.4	4.2	0.54	0.47	
Lorain, OH	17.2	6.5	0.83	0.60	
Tonawanda, NY	17.5	3.5	0.63	0.55	X
Ft. Wayne, IN	34.6	6.7	0.81	0.23	X
South Bend, IN	40.8	2.0	0.33	0.92	X
Grand Rapids, MI	56.5	3.7	0.92	0.47	X
Milwaukee-S., WI 3/	79.0	5.4	0.65	0.36	

1/ Size represents the average flow rate per day experienced in 1982 and 1983 except where otherwise specified.

2/ Phosphorus influent, effluent and cost-effectiveness estimates are simple averages for 1982 and 1983, except where otherwise specified.

3/ 1983 estimates only.

4/ 1982 estimates only.

Source: SAIC, 1988

V. COST-EFFECTIVENESS COMPARISON OF CONSERVATION TILLAGE VERSUS POTWS IN REDUCING PHOSPHORUS POLLUTION

For purposes of this analysis, the cost-effectiveness comparison is restricted to the cost-effectiveness case study of the Honey Creek watershed. The cost-effectiveness of conservation tillage in reducing phosphorus loadings in other watersheds will be highly dependent on the specific characteristics (e.g., soil type, rainfall patterns, slope) of the watershed. Consequently, extrapolating the results to other watersheds can only be done by considering the specific characteristics of the watershed in question.

When considering a specific watershed such as Honey Creek, a comparison of the cost-effectiveness of conservation tillage and publicly owned treatment works (POTWs) in reducing phosphorus loads is difficult due to a number of factors, First, because of the,variability of storm events, the effectiveness of conservation tillage in reducing phosphorus loads will be highly variable; at the same time POTWs can effectively remove specific quantities of phosphorus from influents with much less uncertainty. Second, the cost-effectiveness of POTWs is dependent on their size, with significant economies of scale as indicated in the previous chapter, and it is implicitly assumed that the POTWs serving the Honey Creek watershed are comparable to the other POTWs in the Great Lakes basin which were studied. Third, the cost-effectiveness of conservation tillage depends on the percent reduction in phosphorus pollution targeted for which estimates are provided. However, the POTW cost-effectiveness estimates are based only on costs of reducing phosphorus loads from typically six to eight mg/l to less than one mg/l. Finally, it is important to recognize that other benefits from implementing conservation tillage are not considered, such as reductions in soil erosion and losses of other nutrients; similarly, related beneficial functions of POTWs are not considered, such as removal of other pollutants. Despite these difficulties, some useful conclusions can be drawn about the comparative cost-effectiveness of conservation tillage and POTWs in reducing phosphorus loads.

For purposes of this comparison, only the conservation tillage cost-effectiveness estimates, with no pesticide use restrictions, are considered from Chapter III Limiting the comparison in this manner will result in a more accurate comparison of the actual cost-effectiveness associated with the control of phosphorus pollution.

A. Review of Conservation Tillage Cost-Effectiveness Estimates

As discussed previously, the cost-effectiveness of conservation tillage in reducing phosphorus loads depends on the targeted reduction and the reliability level of meeting the target for any given year. The estimates presented below have the targeted reduction (expressed as a percent of baseline loadings) across the top; the reliability of meeting or exceeding the targeted reduction is listed at the left.

	Targeted reduction in phosphorus pollution (percent of baseline load)			
	10	25	50	75
Percent Reliability 1/	----1985 $/pound----			
50	2/	0.71	5.10	13.20
60	2/	2.57	6.44	18.11
75	5.23	6.75	9.11	34.04
95	25.54	15.06	20.12	3/

1/ Reliability of meeting or exceeding the targeted reduction in any given year.

2/ Cost-effectiveness measure is negative reflecting more profitable tillage practices and crop rotations than initially practiced in the watershed.

3/ Infeasible solution.

For purposes of illustration, consider that it costs an average of $5.10 per pound to reduce phosphorus loadings by 50 percent from baseline conditions. However, this reduction would only be met (or exceeded) in 50 percent of the time periods (years). In the other 50 percent of the time periods, the targeted reduction would not be achieved.

B. Review of POTW Cost-Effectiveness Estimates

The POTW cost-effectiveness estimates, as presented in Chapter IV, are dependent on the size of the POTW in question. As previously discussed, all POTWs studied reduce phosphorus levels ranging from two to 15 mg/l for the influent, to generally less than one mg/l for the effluent. Consequently, POTW costs estimated are associated with reductions in phosphorus levels ranging from 60 to 99 percent (an average of 83 percent).

A summary of the average cost-effectiveness estimates for phosphorus removal as estimated in this study, grouped by POTW size, is presented below:

POTW Size Range (MGD)	Average Cost-effectiveness (1985 $/pound)
< 0.5	9.55
0.5 - 2.0	3.77
> 2.0	2.00

Cost-effectiveness estimates derived in a similar study of primarily larger POTWs -- as presented in Chapter IV, Section D, indicate, substantially lower costs for phosphorus removal. These estimates are presented below for comparative purposes:

POTW Size Range (MGD)	Average Cost-effectiveness (1985 $/pound)
< 5.0	1.37
5.0 - 9.9	1.24
10.0 - 19.9	0.68
20.0 & up	0.41

The analyses did not estimate the impact on costs and cost-effectiveness stemming from incremental increases in the levels of treatment by POTWs, but rather reported the average costs and cost-effectiveness for upgrading from secondary treatment to current levels of phosphorus control (which include phosphorus effluents equivalent to advanced secondary and advanced levels of treatment).

C. Summary

A comparison of the cost-effectiveness of conservation tillage versus POTWs in reducing nonpoint phosphorus loadings requires the consideration of several factors. Of critical importance in assessing the cost-effectiveness of conservation tillage is the desired level of reduction in phosphorus loadings to be achieved and the acceptable reliability (probability) of meeting the desired levels in any given year. Of critical importance in assessing the cost-effectiveness of POTWs is the appropriate size of the facility for the watershed in question.

The higher the targeted reduction in phosphorus loads, the higher the average cost per pound with conservation tillage. In the Honey Creek watershed, POTWs reducing effluent levels to less than one mg/l of phosphorus are cost-effective when targeted reductions are greater than 75 percent, regardless of the size of POTW needed. At targeted reductions of 50 percent, POTWs with capacities greater than 500,000 gallons per day are cost-effective.

At targeted reduction levels of 25 percent, the cost-effective phosphorus control method depends on the desired reliability of achieving the targeted reduction levels in any given year. If meeting the long-run targets is sufficient (i.e., 50 percent reliability assuming the phosphorus loading probability distribution is normal), conservation tillage is more cost-effective except as compared to POTWs treating more than 10.0 MGD of wastewater. If a higher degree of reliability is deemed necessary (i.e., >60 percent) smaller (>2.0 MGD) POTWs are cost-effective.

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APPENDIX A

Review of Cost and Effectiveness Literature on Agricultural BMPs

APPENDIX A

REVIEW OF COST AND EFFECTIVENESS LITERATURE ON AGRICULTURAL BMPs

Practices which reduce soil and nutrient losses from agricultural lands have been studied for a considerable length of time. Many of these studies have focused on the potential of diminished agricultural productivity resulting from soil and nutrient losses. However, more recent studies have centered on agricultural runoff and its contribution to water pollution. In this chapter, published literature regarding the cost and effectiveness of agricultural best management practices is reviewed. The specific BMPs considered are conservation tillage, contouring, terracing, grassed waterways, fertilizer management, sediment basins, livestock exclusions and feedlot runoff management. When possible, studies relating to areas within the Great Lakes Basin are highlighted.

A. Conservation Tillage

Runoff from agricultural land is a major source of nonpoint pollution. Such runoff carries suspended solids, nutrients, pesticides, and organic carbon (Andraski et al., 1983). Of these pollutants, sediment and nutrients are the primary focus of this literature review.

Many researchers believe that the most cost-effective means of reducing contaminant loads from agricultural land is some form of conservation tillage (Mannering et al., 1976; Eckert, 1981; Logan et al., 1982). Conservation tillage systems, which maintain at least 30 percent of the soil surface covered by residue after planting, effectively protect the soil against erosion (Conservation Tillage Information System, 1985). Conservation tillage also affects chemical losses by influencing both the volume of runoff and chemical concentrations in.the runoff (Crosson, 1982).

Some of the varying practices considered to be a conservation tillage sequence as defined by the Conservation Tillage Information Center (1985) include:

<u>No-till</u> - The soil is left undisturbed prior to planting. Planting is completed in a narrow seedbed approximately 1-3 inches wide. Weed control is accomplished primarily with herbicides.

<u>Ridge till</u> - The soil is left undisturbed prior to planting. Approximately 1/3 of the soil surface is tilled at planting with sweeps or row cleaners. Planting is completed on ridges usually 4-6 inches higher than the row middles. Weed control is accomplished with a combination of herbicides and cultivation. Cultivation is used to rebuild ridges.

<u>Strip till</u> - The soil is left undisturbed prior to planting. Approximately 1/3 of the soil surface is tilled at planting time. Tillage in the row may consist of a rototiller, in-row chisel, row cleaners, etc. Weed control is accomplished with a combination of herbicides and cultivation.

<u>Mulch till</u> - The total soil surface is disturbed by tillage prior to planting. Tillage tools such as chisels, field cultivators, discs, sweeps, or blades are used. Weed control is accomplished with a combination of herbicides and cultivation.

<u>Reduced till</u> - Any other tillage and planting system (including slot till, minimum till, chisel till, etc.) not covered above that meets the 30 percent residue requirement.

The common element evidenced in definitions of conservation tillage is the presence of crop residues on the soil surface to reduce water and wind erosion. The plant residue also serves to increase retention of soil moisture.

Comparing the different types of conservation tillage with conventional tillage has revealed differences in effects on runoff, crop yields and net farm income. A review of selected studies is presented in the following discussion and summarized in Table A-1.

1. Costs of Conservation Tillage

With the possible exception of changing machinery complements, there are no direct costs (such as the construction cost of terraces) that can be assessed to conservation tillage. Rather, the cost is usually determined through, the changes in operating and production costs (such as labor, fuel, machinery and pesticides), and changes in yield that occur when switching from conventional tillage to a conservation tillage practice.

a. Changes in production costs (fixed and variable)

Labor. There is general agreement that less labor per acre is needed with conservation tillage than with conventional tillage. The reason is that with conservation tillage, the labor saved by reducing the number of passes over the fields is more than enough to offset any additional labor required for any increased, applications of chemicals for weed, insect or disease control (Crosson, 1982). Triplett and Van Doren (1977) found labor requirements to be three times higher for conventional-tilled. plots when compared with no- till. Conventional-tilled corn in Michigan, Indiana and Nebraska required 1.7, 2.3 and 2.0 times more labor than no-till, respectively (Doster and Phillips, 1973; Mannering and Burwell, 1968, Derschied et al., no date). A 1969 Soil Conservation Service of America. assessment listed percentage reductions in labor requirements for reduced tillage on corn, cotton, sorghum and soybeans to be 52, 58, 52 and 58 percent, respectively. Labor cost in a corn-soybean rotation decreased 31 percent when slot-till was substituted for conventional tillage in Iowa (Jolly et al., 1983). Another field trial on soybeans in Iowa showed labor requirements for no-till were 46 percent lower than plowing and discing (Crosson, 1982).

Table A-1. Summary of conservation literature regarding the reduction of phosphorus losses

Reference	Study location	Grade of slope	Crop	Conventional tillage: Soil loss	Conventional tillage: Phosphorus loss	Conservation tillage: Practice 1/	Conservation tillage: Soil loss	Conservation tillage: Phosphorus loss	Percent change due to conservation tillage: Soil loss	Percent change due to conservation tillage: Phosphorus loss	Percent change in total production cost due to conservation tillage	Percent change in crop yield due to conservation tillage
		%		tons/acre per year	lbs/acre per year		tons/acre per year	lbs/acre per year				
Defiance Conservation District, 1984	Ohio	1-3	Corn	5.6	-	R-T	2.3	-	-59	-	-	-
						N-T	1.0	-	-82	-	-	-7
			Soybean	5.0	-	R-T	2.3	-	-54	-	-	-
						N-T	1.3	-	-74	-	-	3
Harrold et al., 1972	Ohio	-	Corn	22.7	-	N-T	.03	-	-99	-	-	-
Griffith et al., 1977	Ohio		Corn	-	-	N-T	-	-	-	-	-	10
Doster, 1976	Indiana		Soybean	-	-	N-T	-	-	-	-	-	21
Logan, et al., 1982	Michigan	3	Corn	2.2	-	R-T	1.2	-	-45	-	-	-
						N-T	.7	-	-68	-	-	-
U.S. Corps of Engineers, 1981	Ohio	-	Corn	6.9	.79	R-T	4.7	.56	-32	-26	-6	-
						N-T	1.4	.22	-80	-64	-3	-
Logan and Forster, 1982	Ohio	-	-	-	-	N-T	-	-	-	-60	-	-
Mueller et al., 1983	Wisconsin	6	Corn	-	-	Ch	-	-	-60	-58	-	-
						N-T	-	-	-73	-70	-	-
Andraski, 1983	Wisconsin	6	Corn	-	-	Ch	-	-	-64	-	-	-
						N-T	-	-	-88	-	-	-
Logan and Adams, 1981	Ohio	-	-	-	-	N-T	-	-	-90	-80	-	-
Colvin et al., no date	Iowa	-	Corn	-	-	T-P	-	-	-	-	-10	-43
			Soybean	-	-	T-P	-	-	-	-	-9	-19
Colvin et al., 1983	Iowa	5	Corn	36.9	-	N-T	10.5	-	-72	-	-5	2
			Soybean	30.1	-	N-T	12.3	-	-59	-	-5	-9
Ervin et al., 1983	Missouri	3	Corn	12.5	-	R-T	8.6	-	-31	-	-2	-
						N-T	5.2	-	-58	-	8	-
Jolly et al., 1983	Iowa	1-4	Corn	5-15	-	S-T	1-2	-	-93	-	1	-6
			Soybean	3-12	-	S-T	0	-	-100	-	2	2
Erbach, 1982	Iowa	1-4	Corn	-	-	Ch	-	-	-	-	-	-13
						N-T	-	-	-	-	-	-6
						Ch	-	-	-	-	-	0
						N-T	-	-	-	-	-	-4

1/ R-T = Reduced Tillage; T-P = Tillage Plant; N-T = No-Till; S-T = Slot-Till; Ch = Chisel

Shipley and Osborn (1973) estimated the ratio of labor used with conventional tillage to that used with conservation tillage to be 1.7 for continuous grain sorghum and 1.75 for a wheat-grain sorghum rotation. The importance of the difference in labor requirements in each situation depends upon the magnitude of labor costs in relation to total costs, exclusive of the cost of land (Crosson, 1982).

Machinery and Fuel. Though varying in magnitude by site and study, information on machinery requirements and fuel consumption for various tillage practices indicate savings when using conservation tillage.

Conservation tillage systems can reduce machinery-related costs in three ways: fewer trips require less fuel; fewer machinery items are needed; and because fewer operations are performed, smaller machinery can be used without sacrificing timeliness of planting (Jolly et al., 1983). The savings resulting from fewer trips across the field are noticeable immediately. The savings in ownership costs, however, come about only as changes in the machinery complement are made. If larger machinery is kept for occasional use, machinery ownership costs will remain unchanged. The machinery usage costs per acre for a corn-soybean rotation were estimated to be $54.84, $46.10 and $28.56 for conventional tillage, reduced tillage, and slot-till, respectively (Hamlett et al., 1983). Machinery ownership costs in the Jolley study were 25 percent lower for slot-till when compared to conventional tillage.

Fuel savings of up to 73 percent have been reported for growing corn under no-tillage as compared to conventional tillage (Crosson, 1982). Data developed by the Iowa Cooperative Extension Service (1976) for fuel requirements for various rotations and tillage systems show a decrease of about 50 percent in the use of fuel between fall moldboard plow and no-till systems for both continuous corn and a corn-beans rotation in loam soil. Economic analysis of a four-year project in Defiance County, Ohio (1983) showed machinery costs for no-till soybeans were 53 percent lower than conventional tillage and a greater difference was experienced with corn (66 percent). For a 500-acre corn-soybean operation in Illinois, Siemens and Oschwald (1978) observed machinery costs to be 4 percent lower for chisel and 20 percent lower for no-till as compared to a conventional tillage operation. On a similar 1,000-acre plot, the differences for chisel and no-till increased to 11 and 33 percent, respectively.

A study of fuel consumption of tillage systems under Oklahoma conditions showed that conservation tillage saved 1 to 3 gallons of diesel fuel per acre relative to moldboard plow farming (American Society of Agronomy, undated). Fuel requirements for reduced till and no-till were recorded as being 20 percent and 48 percent lower, respectively, for corn in South Dakota (Derscheid et al., undated).

<u>Herbicides</u>. Conservation tillage generally relies more on herbicides and less on cultivation to control weeds than does conventional tillage; however, studies of herbicide use with different tillage practices have shown mixed results. Phillips et al. (1980) state that a reduction in tillage generally requires an increase in the reliance on herbicides, and that no-till corn requires about 50 percent more herbicides than conventionally-tilled corn. Jolly et al. (1983), however, found an increase in herbicide use of only 14 percent over conventional tillage when slot-till practices were implemented in a corn-soybean operation in Iowa. If the switch from conventional tillage is to reduced or minimum tillage, there is often no increase in herbicide cost (Colvin et al., 1983; Ervin et al., 1983; Laflen et al., 1983). Doster and Phillips (1973), analyzing corn production in central Indiana, also show identical costs for herbicides with conventional tillage and.three kinds of conservation tillage. They indicate, however, that with "true" no-till, herbicide costs would be 50 percent higher. Griffith and Parsons (1980) report that in changing from conventional to no-till corn, herbicide application increases 43 percent. Chisel plowing requires a 14 percent increase in herbicide use over conventional tillage.

A Lake Erie Demonstration Report combined the analyses of a number of applications and amounts, and determined that although farmers increased the number of herbicides used, they tended to decrease the amount of any one herbicide that was used (U.S. Army Corps of Engineers, 1983). Thus, although one more herbicide application was made on no-till corn as compared to conventionally-tilled corn, farmers tended to use only 80 percent as much of any individual herbicide on no-till corn. Total herbicide usage oh no-till corn, however, was still 12 percent greater than on conventionally-tilled corn in the project (U.S. Army Corps of Engineers, 1983).

Taylor et al. (1979) show identical herbicide costs for conventional and "limited" tillage systems to produce irrigated winter wheat in Texas. With no-till, however, herbicide costs were estimated to be 350 percent higher.

More information is needed on long-term herbicide use under no-till. One theory is that once control is established on a field, less herbicide is actually needed since dormant weed seeds are not tilled up to the surface to begin growing. Also, excess herbicides may be used during the first years to ensure results while the operator is still learning about no-till management techniques (Fuller, 1985).

b. Changes in yield

The variability in yield results from conventional tillage and conservation tillage field and plot test comparisons limits the value of applying generalizations about yield effects to specific sites. Yields with conservation tillage are greater, lower, or about the same as compared with conventional tillage, and are related to such site-specific characteristics as crop, soil type, rainfall and climate. Three-year averages for the Honey Creek watershed (Ohio) showed that corn yields decreased 3 and 10 percent with reduced and no-till, respectively, when compared to conventional till. In the same study, reduced-till soybean yields decreased 7 percent while no-till yields increased by 3 percent (U.S. Army Corps of Engineers, 1982). In the Lake Erie Basin, Bone et al. (1977)

found four-year average corn yields were 11 percent higher with no-till versus fall plow. A summary of no-tillage yield potentials in Ohio (Forster, 1976) indicate yield increases of approximately 10 percent on well-drained soils (relative to conventional tillage), approximately equal yields on moderately to somewhat poorly-drained soils, and yield decreases in the order of 10 percent on poorly and very poorly-drained soils.

In Iowa, average corn yields over a five-year period were slightly lower with strip and slot-till systems than with conventional till. However, yields varied more among years than among production systems (Jolly et al., 1983). Also in Iowa, Erbach (1982) looked at various conservation practices and their corresponding yields over a five-year period. The fall moldboard plow system had the highest five-year average yield for continuous corn production. In this study, tillage systems did not significantly affect yields of either corn or soybeans in the corn-soybean rotation. These results were similar to those of Siemens and Oschwald (1978) where yields tended to be lower with conservation tillage. Colvin et al. (1983) analyzed Iowa corn-soybean rotations for three years to observe the yield difference (if any) between conventional tillage and ridge-till planting. For two of the three years, yields were slightly higher with the conventional practice. Results from Cruse's 1983 study of corn yields in Iowa indicated that in 1980 and 1981, when rainfall averaged 10 inches above normal for that location, the yield of no-till corn was lower and significantly different from corn yields on the reduced-tillage and conventional-tillage plots. However, in 1982, when rainfall was only slightly above normal for the area, corn yields for all three tillage systems were comparable.

2. Effectiveness of Conservation Tillage in Reducing Nonpoint Pollution

The effectiveness of conservation tillage in reducing nonpoint pollution is more complicated than simply looking at the effectiveness in controlling erosion. Most of the conservation tillage practices were designed for erosion control rather than nutrient management. However with erosion control, there is always control of the particulate phosphate fraction and the dissolved phosphate load may also be reduced (Logan et al., 1982). The following discussion will emphasize results concerning soil loss, water runoff and phosphorus levels leaving agricultural fields.

a. Reductions in soil loss and runoff

Plant residue on the soil surface serves to protect the soil from raindrop impact and will help prevent soils with poor surface structure from crusting and sealing. Residue also increases surface roughness compared to conventionally-tilled soil. These factors should allow increased infiltration and reduced runoff with no-till or other tillage systems which maintain a high degree of cover (Logan et al., 1981). However, other factors may cause somewhat variable results.

Johnson et al. (1979) found runoff decreased by 54 percent when no-till corn replaced conventional-tilled corn. Smith et al. (1979), however, showed that no-till runoff was 10 to 30 percent higher in three out of four years. Logan et al. (1981) concluded that no-till increases runoff compared to conventional tillage with soils that have poor internal drainage or have restricted.subsurface drainage, while no-till decreases runoff on soils that are more permeable.

Over a three-year period at the Honey Creek Watershed Project, reduced tillage lowered soil loss by 30 percent and no-till lowered it by 77 percent, as compared with the conventional-till plots. Over a three-year field trial in Iowa, Colvin et al. (1983) concluded that conventional plowed treatment would average almost five times as much erosion as the no-till plots for both soybeans and corn.

Field data for soybeans in Ohio showed the reduction in soil loss to be 30 and 70 percent for reduced and no-tilled corn,. respectively, when compared with conventional tillage (Defiance Soil and Water Conservation District, 1984). Wischmeier (1973) found that soil lost to water erosion was inversely related to the percentage of the soil surface covered by residue. He also found that surface cover was far more important than any other factor in reducing erosion.

Both simulated and natural rainfall were used in a Wisconsin study to observe the impacts of tillage systems on runoff and soil loss (Andraski et al., 1983). At high simulated rainfall intensity, reductions in runoff of 38, 21 and 23 percent were observed from chisel plant, reduced till, and no-till systems, respectively. The percent reductions in runoff for lower intensity rainfall periods in two years of study were as follows: no-till (56, 69 percent), reduced till (42, 68 percent), and chisel (38, 67 percent). Under natural rainfall, conservation tillage reduced runoff losses by 85 to 90 percent compared to conventional tillage over a two-year period. No-till and reduced-till treatments (simulated rainfall) had significantly lower soil losses than the conventional treatment for all three rainfalls. The percent reductions in soil loss relative to conventional tillage for the two low and one high intensity rainfall were 89, 85 and 91 percent for no-till, 61, 60 and 87 percent for reduced till and 60, 46 and 87 percent for chisel till. Observations by Andraski et al. noted the following: 1) among the three conservation systems, although chisel and reduced till result in approximately 45 percent of the residue cover as under no-till, runoff losses were not significantly different and 2) soil losses among the conservation treatments were significantly less from the. no-till system for the two 1983 sampling periods.

b. Changes in phosphorus levels leaving the field.

Recently, conservation tillage methods have received considerable attention as management alternatives for reducing pollutant loads in agricultural runoff. The majority of phosphorus (P) in agricultural runoff is normally attached (adsorbed) to sediment. Because of this, erosion control practices show promise for reducing total phosphorus (TP) in runoff and, accordingly, TP inputs to surface waters (Mueller et al., 1983). While some studies have shown that practices which reduce erosion also decrease

TP losses (Romkens et al., 1973; Siemens and Oschwald, 1976), others have also shown that soluble P concentrations and losses (which are a relatively small portion of TP) may be greater with conservation tillage (Barisas et al., 1978; McDowell and McGregor, 1980). Researchers have also observed that higher concentrations of soluble P may be primarily attributed to a lack of incorporation of fertilizer P and to a release of P from crop residue (Timmons et al., 1973).

Using simulated rainfall on corn plots in, Wisconsin, Mueller et al. (1983) determined that concentrations of TP in runoff were significantly reduced at no-till sites compared to conventional or chisel till sites. Actual reductions for no-till averaged 79 percent. Final evaluation of the three-year Honey Creek watershed study (U.S. Army Corps of Engineers, 1981) revealed that reduced tillage lowered TP in runoff by 26 percent as compared with conventional tillage. No-till reduced TP in runoff by 64 percent. Logan and Adams (1981) indicated that conservation tillage greatly reduced soil loss and TP loss, but the percent reduction of TP was 89 percent of the reduction in soil loss. Allen et al. (1980) studied erosion, runoff, and nutrient loss with conventional tillage and conservation tillage in six small watersheds in western Iowa over a four-year period. They found that although the concentration of available (dissolved) P was about three times higher in soil eroded from conservation-tilled fields, loss of TP was typically less with conservation tillage because erosion was significantly reduced.

c. Factors affecting results of conservation tillage

As supported above, conservation tillage generally reduces soil loss when compared with conventional tillage. However, its effects on crop yields are not always beneficial. Unfortunately, even with the knowledge of tillage system requirements now available, crop yields may not always equal yields obtained with conventional tillage on some soils. For the most part, reduced crop yields attributed to the use of conservation tillage have been associated with particular soils having inherent physical limitations. These include drainage problems, soil wetness levels (both degree and frequency of wetness), structural stability, water percolation, impervious or restrictive layers in the soil profile, and surface soil texture (Cosper, 1983; Mueller et al., 1983).

Runoff will transport less P to water bodies when conservation tillage is practiced, but the concentrations transported by runoff water can be higher. The net outcome will therefore vary from situation to situation (Crosson, 1982). If phosphorus fertilizer is not banded or drilled into the field at the time of application, phosphorus losses may be higher with conservation tillage because this practice disturbs the topsoil less (Logan and Adams, 1981). Mueller et al. (1983) supports this theory and concludes that higher concentrations of soluble P are primarily attributable to a lack of incorporation of fertilizer P and to a release of P from crop residue.

The fact that conservation tillage leaves more residue on the surface is the primary reason that soil loss is always less on these plots. Wischmeier (1973) found that soil lost to water erosion was inversely related to the percentage of the soil surface covered by residue. He also found that surface cover was far more important than any other factor in reducing erosion with conservation tillage relative to conventional tillage.

B. Contouring

Contouring, which is one of the oldest conservation techniques used in the U.S., involves plowing, planting and harvesting in a direction perpendicular to the slope of the land. The contour furrows catch and hold water during rainstorms and reduce runoff velocity, thereby increasing the time for infiltration and reducing erosion. Contouring is frequently practiced on gentle slopes since it is most effective on a three to seven percent grade (Beasley et al., 1984). Contouring is generally used with strip cropping; however, it can also be effectively used in combination with other conservation practices such as conservation tillage, terracing, and terracing with grassed waterways.

Numerous studies have examined the effect of contouring in reducing both soil and phosphorus losses. Other studies have estimated costs for the initial contouring and subsequent annual costs. A synopsis of cost and effectiveness studies of contouring is contained in Table A-2. A general discussion of cost and effectiveness of contouring in controlling soil erosion and phosphorus losses is presented below.

1. Costs of Contouring

Little data are available on contouring costs because, like conservation tillage, the costs are represented by increased labor requirements due to a decrease in efficiency. In addition to the initial investment costs, the cost of contouring is largely associated with reduced efficiency of labor and machinery due to irregular cultivating, planting and harvesting patterns that would not have been followed with conventional tillage. Marginal cost estimates of reduced labor efficiency are reasonably straightforward, being based on an hourly wage. However, costs associated with decreased machinery efficiency are considerably more difficult to estimate.

a. Initial investment cost

Initial investment expenditures are required for the surveying of the land to be contoured, and development of the contoured fields. Field boundaries must carefully be set so that they are plowed perpendicular to the slope of the land; accordingly, the greater degree of fluctuation in topography, the higher the implementation cost. Land which has been under straight-row tillage may have developed gullies from erosion; consequently, investment costs will vary depending on the work necessary to eliminate gullies or other irregularities on the land to be contoured.

Table A-2. Summary of contouring cost and effectiveness literature regarding the reduction of phosphorus and sediment losses

Reference	Study location	Grade of slope	Crop	Uncontoured Soil loss	Uncontoured Phosphorus loss	Contoured Soil loss	Contoured Phosphorus loss	Percent reduction Soil loss	Percent reduction Phosphorus loss	Contouring costs Investment	Contouring costs O&M	Increase in crop yield	Cost effectiveness in edge of field reduction of Sediment	Cost effectiveness in edge of field reduction of Phosphorus
		(%)		tons/acre per year	lbs/acre per year	tons/acre per year	lbs/acre per year			---dollars/acre---		(%)	---dollars per pound--	
Van Doren et al., 1950	Illinois	2	Corn	3.7	-	2.2	-	41	-	-	-	3	-	-
	Illinois	2	Soybeans	2.7	-	0.6	-	78	-	-	-	5	-	-
	Illinois	2	Oats	0.8	-	0.5	-	38	-	-	-	-	-	-
Bedell et al., 1946	Indiana	2-5	Corn	4.0	11.8	0.9	3.1	78	74	-	-	-	-	-
	Indiana	2-5	Wheat	0.8	2.6	0.1	0.4	88	85	-	-	-	-	-
International Joint Comm., 1983	-	2-8	-	-	-	-	-	50	35	-	-	-	-	14-23
Lewis, 1985	Illinois	-	-	-	-	-	-	-	-	11	0-1	-	0.2-0.3	-
Lake and Morrison, 1977	Indiana	-	-	-	-	-	-	-	-	2	-	-	-	-
Moldenhauer and Wischmeier, 1960	Iowa	12	Corn	25.0	-	10.0	-	60	-	-	-	-	-	-
Onstad, 1972	South Dakota	6	Corn	2.7	-	0.4	-	85	-	-	-	3	-	-
Carter et al., 1968	Mississippi	5	Corn	-	-	-	-	72	-	-	-	-	-	-
Stallings, 1945	-	-	Corn	-	-	-	-	-	-	-	-	17	-	-
	-	-	Soybeans	-	-	-	-	-	-	-	-	14	-	-
Toups Corp., 1977	Colorado	2-8	-	-	-	-	-	40-60	-	-	3-5	-	-	-
Smith et al., 1979	-	-	Corn	-	-	-	-	-	-	-	3-4	0-5	-	-
Quinn et al., 1984 1/	New York	-	Row crops	3.0	1.9	2.3	1.3	24	28	-	5	-	-	10

1/ Data on phosphorus reductions are for in-stream losses, not edge of field losses.

Few estimates are available regarding investment costs for contouring, and little detail is provided in these studies regarding how the estimates were derived. In Allen County, Indiana, installation costs were estimated at $2 per acre in the Black Creek watershed. This watershed was chosen for a comprehensive study of agricultural BMPs, of which contouring was a relatively minor component, being used on only 769 acres (Lake and Morrison, 1977). Average installation cost estimates in Illinois were $11. per acre for contour strip cropping. These costs, estimated as a statewide average by the Soil Conservation Service, are used for cost-sharing estimates (Lewis, 1985). Cost estimates by the Agriculture Stabilization and Conservation Service (ASCS) in 1983 were as high as $29 per acre (EPA, 1984). Unfortunately few details were available regarding this estimate. Apparently ASCS does not have a cost-sharing program for contouring in most states (with the exception of Illinois) and, accordingly, does not have extensive cost data for contouring.

b. Operation and maintenance costs

Operation and maintenance (O&M) costs associated with contouring are generally quite site specific and thus highly variable. The major expenses include additional labor and equipment costs required to plow according to field topography. In addition, some land may effectively be taken out of production because the end rows may be too narrow to be tilled effectively.

Smith et al. (1979) estimated that O&M costs would increase by 10 percent over straight row tillage for a total increase of $3 to $4 per acre in typical situations throughout the U.S. However, they also noted that O&M costs could be 30 to 40 percent higher than straight row tillage in extreme situations. Quinn et al. (1984) used the study by Smith et al. and estimated O&M costs to be over $5 per acre. In a study in Colorado, O&M costs associated with contouring were estimated to range from $3 to $5 per acre (Toups Corp., 1977). This estimate is in agreement with the Minnesota Soil Conservation Service (SCS) estimate of $4 per acre (Dansdill, 1985).

c. Crop yields

Some studies have indicated potential for increases in crop yields on contoured versus uncontoured cropland. Because the contoured furrows slow runoff and thereby increase infiltration, additional moisture is available for the crops grown. Accordingly, in dry years, yields are expected to be increased over straight-row planted fields; conversely, in wet years or on poorly drained soils, crop yields may be lower (Smith et al., 1979). Few recent studies have documented changes in yields on contoured fields, however. Stallings (1945), in a review of other studies, found that the average increase in corn yields was 17 percent while soybean yields increased by 14 percent. These studies were conducted in many different states and under various growing conditions. Van Doren et al. (1950) in an Illinois study found that corn yields were nearly three percent higher on contoured versus straight row plots for the nine crop years studied; increases in yields on contoured soybeans were approximately five percent greater than on straight row soybeans. Similar results were also obtained in studies in South Dakota (Onstad, 1972).

2. Effectiveness of Contouring in Reducing Nonpoint Pollution

Contour tillage is an important practice in the control of soil and phosphorus losses. It is inexpensive and in many cases easily applied. However, since contouring is generally used in conjunction with other conservation practices, there are few studies that show the effectiveness of the practice itself. Furthermore, most studies concerned with contouring do not estimate reductions in phosphorus losses.

Contour tillage is most effective on moderate slopes and topography and is considered more effective on well-drained soils and in areas without high rainfall. A discussion of the effectiveness of contouring in reducing soil and phosphorus loss is presented in the following sections.

a. Reduction in soil and phosphorus losses

In a study conducted in Illinois (Van Doren et al., 1950) contour tillage was found to be effective in reducing soil losses. On plots with a two percent slope, soil losses were reduced by 1.3 tons per acre (41 percent) for corn, 2.1 tons per acre (78 percent) for soybeans and 0.3 tons per acre (38 percent) for bats. Researchers concluded that soil losses were considerably lower from soybean than corn crops because soybean plants develop much faster. Also, both soybeans and oats are normally planted closer together helping to reduce soil losses. In these trials an analysis was also made of dissolved P losses in runoff; however, traces of phosphorus were too small to measure (Van Doren et al., 1950). Apparently, no analysis was completed regarding phosphorus losses adsorbed to the eroded sediment.

Bedell et al. (1946) studied the effects of several conservation practices, including contour tillage, on sediment and phosphorus losses. Sediment losses from corn and wheat crops, planted on fields with a slope of two to five percent, were reduced by 78 and 88 percent, respectively. Reductions in phosphorus losses were also considerable, although these data must be interpreted with some caution because of the field conditions at the time. In these experiments, contouring was combined with higher levels of fertilization, including applications of manure; consequently, additional phosphorus was available for possible erosion. Nevertheless, total phosphorus losses were reduced by 74 and 85 percent from the corn and wheat fields, respectively.

In Iowa, soil erosion on test plots with a 12 percent slope averaged 25 tons per acre. Contouring reduced this loss by 60 percent to only 10 tons per acre (Moldenhauer and Wischmeier, 1960). The authors concluded that the effectiveness of contouring decreased as storm erosivity increased and for very erosive storms, soil loss from contouring exceeded that from straight row planting. It is important to note that in these plot tests, the plots were only 73 feet long (which was determined to be the average length of slope). Accordingly this artificial restriction on slope length may have resulted in better erosion control than would actually be obtained on a typical field with the same grade of slope (Moldenhauer and Wischmeier, 1960).

Contour tillage of corn moderate slopes in eastern South Dakota was found to be very effective in controlling soil erosion. In six years of plot tests, soil erosion from contoured plots was reduced by nearly 2.3 tons per acre (85 percent) from conventionally tilled plots. However, Onstad (1972) noted that in actual field conditions where the slope length is not restricted by the size of the plot (in this case, 73 feet), contouring may not be as effective. On longer slopes, rainwater may be more likely to wash over furrows and not effectively limit erosion as on slopes with a maximum length of 73 feet.

In northern Mississippi, contour tillage of corn was found to decrease soil loss on highly erodible soils by over 70 percent. The slope length on all plots in these tests was also limited to 73 feet (Carter et al., 1968).

Reduction in soil loss as a result of contouring on gentle slopes with a two to eight percent grade is generally in the range of 40 to 60 percent, according to several studies of published literature. For example, the International Joint Commission (1983) concluded that soil losses could be reduced by 50 percent due to implementation of contour tillage in the Great Lakes Basin. This conclusion was based on a review of numerous studies, many of which were based in Ontario, Canada (Bos, 1983; International Joint Commission, 1983).

Some studies concluded that contouring was also effective in reducing phosphorus losses. Reductions of total phosphorus loss generally ranged from 35 to 65 percent (Bos, 1983; International Joint Commission, 1983); however, the reduction was only 25 percent for soluble phosphorus (Logan and Forster, 1982).

b. Factors affecting contouring effectiveness

Numerous factors are responsible for determining the effectiveness of contouring in controlling soil and nutrient losses. Variations in weather patterns from one year to the next can considerably affect soil and phosphorus losses on a contoured field, as was shown by research in Iowa (Haith, 1979). If heavy rainfall occurs over a short period of time, the contoured furrows may be washed over with soil and nutrients washed away at a rate even higher than straight-row tillage (Onstad, 1972; Smith et al., 1979). Also, since contouring reduces soil and nutrient loss by increasing infiltration, it is more effective on permeable soil than on soil of high clay content (Humenik et al., 1982).

While rainfall patterns and soil types are important factors in determining the effectiveness of contouring in controlling soil and phosphorus losses, probably the most critical factors are slope and slope length. Contouring is generally only effective on slopes with a grade ranging from two to eight percent; even over this range of slope, the effectiveness of contouring varies inversely with percent slope. According to one study, contouring will reduce erosion by less than 10 percent on slopes of 18 to 24 percent (Bos, 1983). In addition to slope, length of slope is also critical when rainfall exceeds infiltration capacity and surface detention. Break-overs of contour rows often result in concentrations of runoff that tend to become progressively greater with increases in slope length. Therefore, on slopes exceeding some critical length, the amount of soil removed from a contoured field may approach or exceed that from a field on which each row carries its own runoff water down the slope. The slope length at which this could be expected to occur depends on field gradient, soil properties, cultivation practices, and storm characteristics (Wischmeier and Smith, 1978). Finally, topography is also a critical factor in determining the effectiveness of contouring. Contoured fields must be free of gullies or other irregularities to effectively control erosion of soil and phosphorus.

C. Terraces

Terraces, along with strip cropping and contour tillage, are support practices that complement the more cultural and management types of erosion control practices, such as crop rotation and conservation tillage. A terrace is an earthen embankment, channel, or combination of ridge and channel constructed across a slope (Highfill, 1983). Terraces are designed to reduce sheet and rill erosion between terraced sections by reducing slope run lengths. Also, deposition along the terraces may trap the sediment eroded from above. Deposited sediment thus remains on the field and is then redistributed by the farmer, thereby reducing the deterioration caused by erosion (Foster and Highfill, 1983).

Terraces are classified according to alignment, cross section, grade and type of outlet. Alignment can be parallel or nonparallel. There are four main classes of terrace cross sections. Broad-base terraces are constructed so that the entire ridge and channel can be planted and harvested. Flat-channel terraces feature level benches that store runoff for use by crops. Steep-backslope terraces have ridges constructed wholly or in part of soil from the downhill side of the ridge. The steep backslopes are not cropped but instead devoted to permanent plant cover. Narrow-base terraces are similar to steep-backslope terraces, but both sides of the ridge are steep and planted to permanent vegetative cover. By grade, terraces are classified as either gradient or level. Gradient terraces are constructed with sufficient slope to the outlet so that runoff is removed with minimal erosion. Level terraces are constructed so that runoff seeps into the soil, either to conserve moisture, reduce erosion, or both. Outlets can include grassed waterways, wooded draws, drop structures, and drain tiles.

In the past ten years, there have been numerous studies on the impacts of terraces on soil erosion and nutrient loss from agricultural fields. The methodologies have varied greatly in their use of actual field data, simulation models, and combinations of the two. Several studies examined the effectiveness of terracing in reducing phosphorus loss but none that were reviewed actually calculated the cost-effectiveness of terraces in reducing phosphorus loss. A general summary of cost and effectiveness of terracing in controlling soil and nutrient loss is presented below and summarized in Table A-3.

1. Costs of Terracing

Because each terrace installation must be designed to meet the particular characteristics of that site, the costs of terracing are very site specific. While the base price (i.e., price per linear foot) is fairly constant for a given type of structure, the actual size or linear feet of terrace per acre varies from location to location. To determine the cost for terraces, researchers have generally combined the yearly operation and maintenance estimates with an annualized establishment (installation) cost discounted over the expected life of the structure.

a. Initial investment cost

Investment costs include the use of equipment and labor for the construction of the terrace. Terraces can be constructed with a moldboard disc or plow, terracing bulldozer, scraper, or similar equipment. There may also be engineering costs for the planning and placement of terraces, but often these are provided by local Soil Conservation Service personnel at little or no cost to the landowner.

At the Black Creek watershed in Indiana, investment costs were estimated at $0.25/foot for gradient terraces, $0.75/foot for parallel terraces and $1.00/foot for parallel terraces with tile outlets (PTO) (Lake and Morrison, 1977). Per acre estimates can vary greatly even within studies, depending upon soil series and topographies assumed or recorded. In Bos's. (1983) review of conservation literature, he found actual field data on terrace establishment costs to vary from $296 to $815 per acre of terrace in the Great Lakes Basin. The economic life of terraces is usually estimated to be from 15 to 20 years (Haith and Loehr, 1972; META, 1979).

Table A-3. Summary of terracing cost and effectiveness literature regarding the reduction of phosphorus and sediment losses

Reference	Study location	Grade of slope	Crop	Unterraced Soil loss	Unterraced Phosphorus loss	Terraced Soil loss	Terraced Phosphorus loss	Percent reduction Soil loss	Percent reduction Phosphorus loss	Terracing cost Investment	Terracing cost O&M	Change in crop yields	Cost effectiveness in edge of field reduction of Soil loss	Cost effectiveness in edge of field reduction of Phosphorus
		(%)		tons/acre per year	lbs/acre per year	tons/acre per year	lbs/acre per year			----dollars/unit----		(%)	------dollars/unit------	
META, 1979	Indiana	4-12	Corn	26.5	-	18.9	-	29	-	252.00/acre	28.30	+5.5	3.72 per ton	-
Lake and Morrison, 1977	Indiana	-	-	-	-	-	-	-	-	.25/ft GN 1/ .75/ft GP 1.00/ft GPTO	-	-	-	-
International Joint Commission, Nonpoint Task Force, 1983	Great Lakes Basin	-	-	-	-	-	-	90	75	-	-	land was lost 2/	-	-
Bos, 1983	Great Lakes Basin	-	-	-	-	-	-	90	75	296-815/acre	14.80-40.75	-	-	-
EPA Report to Congress, 1984	-	-	-	-	-	-	-	50-90	-	73/acre	16	-	7.00 per ton	-
Lewis, 1985	Illinois	-	-	-	-	-	-	-	-	- .89/ft GN .97/ft GS 1.42/ft LB 1.11/ft LN 1.22/ft LS	1.11/ft GB .13 .15 .22 .17 .19	.17		
Clark, 1985	Michigan	-	-	-	-	-	-	-	-	-	.3[illegible]/ft GN	.06		
George, 1981	Oregon	-	Wheat	27	-	10	-	63	-	-	-	-	-	-
Carter, et al., 1968	Georgia	-	Corn	-	-	-	-	50	-	-	-	-	-	-
Alberts, et al., 1978	Missouri Valley	-	Corn	5	-	1.4	-	73	-	-	-	-	-	-
Spomer, et al., 1973	Missouri Valley	2-16	Corn	25	-	1	-	96	-	38.95/acre	2.47	-6	1.57 per ton	-
Burwell et al., 1974	Southwest Iowa	6	Corn-Soybeans	10.43	1.18	.49	.58	95	50	-	-	-	-	-

Table A-3. (continued)

Reference	Study location	Grade of slope	Crop	Unterraced Soil loss	Unterraced Phosphorus loss	Terraced Soil loss	Terraced Phosphorus loss	Percent reduction Soil loss	Percent reduction Phosphorus loss	Terracing cost Investment	Terracing cost O&M	Change in crop yields	Cost effectiveness in edge of field reduction of Soil loss	Cost effectiveness in edge of field reduction of Phosphorus
		(%)		tons/ acre per year	lbs/ acre per year	tons/ acre per year	lbs/ acre per year			------dollars/unit------		(%)	-------dollars/unit-------	
Burwell, et al., 1968	-	-	Corn	10	-	.5	-	.95	-	-	-	-	-	-
Mussetter	Iowa	-	-	-	-	-	-	-	-	-	.50/ft GNP	.09		
										1.00/ft GP	.18			
										2.00/ft GPTO	.37			
										.55/ft LNP	.10			
										.90/ft LP	.17			
										1.20/ft LPTO	.22			

1/ GB - Gradient Broad Base
GN - Gradient Narrow Base
GS - Gradient Steep Backslope
LB - Level Broad Base
LN - Level Narrow Base
LS - Level Steep Backslope
GNP - Gradient Nonparallel
GP - Gradient Parallel
GPTO - Gradient Parallel Tile Outlet
LNP - Level Nonparallel
LP - Level Parallel
LPTO - Level Parallel Tile Outlet

2/ Quantity undefined.

b. Maintenance costs

Terrace systems require frequent maintenance if they are to function properly. Keeping the terrace channel from filling up with sedimentation is one of the maintenance requirements for terraces. The other is upkeep of the outlet, if there is one (tile, grassed waterway, or drop structure). Again, this cost is directly related to the size and number of terraces. While some prefer to estimate the cost as a percent of the initial investment, usually three percent (Spomer et al., 1974; Lake and Morrison, 1977), others have used a flat rate such as $0.30/ft and $28/cropland acre (META, 1979; Lewis, 1985). Upkeep of the terrace and its outlet help extend the useful life of the terrace, and hence its cost-effectiveness (Walker 1977).

c. Effects on variable costs and yields

When terraces are constructed, some portion of the acreage base is generally lost. Some of the associated yield that is lost, however, may be offset by productivity gains on remaining acres. The general consensus is that crop yields may increase in dry areas in which terraces have been built to collect rainfall and conserve soil moisture, but a negative impact results in wetter areas, especially on land that is poorly drained (Carter et al., 1968; George et al., 1978; META, 1983). In 1945, Stallings noted yield increases of 36 percent in sorghum, 55 percent in wheat, 42 percent in cotton, 6 percent in corn and 4 percent in oats on dry areas. that had been terraced.

2. Effectiveness of Terracing in Reducing Nonpoint Pollution

The purpose of a terrace system (terraces and outlets) is to provide an orderly removal of runoff water. Terraces have proven to be effective in reducing transport of eroded soils from fields, although they require soil disturbance and are expensive to build. In addition to allowing time for soil particles (and the nutrients therein) to settle out of suspension, ponding of runoff behind terraces can increase infiltration and therefore reduce surface runoff. A discussion of the effectiveness of terracing in reducing soil and phosphorus loss is presented in the following sections.

a. Reduction in soil and phosphorus losses

Burwell et al. (1974) used field data collected during a two-year study in Iowa to determine the quality of water leaving a 390-acre level terraced watershed. To evaluate the influence of the terraces on sediment and nutrients in runoff water, data obtained from the watershed were compared to an 83-acre contour planted corn cropped watershed located 11 miles away. Slopes ranged from 2 to 13 percent, and the soil was considered to be naturally erosive. Based upon a two-year average, sediment loss from the terraced field was four percent of the level recorded from the unterraced watershed. Total phosphorus runoff was 54 percent lower from the terraced watershed than from the unterraced watershed over the two-year period. Spomer et al. (1973), in a study in the Missouri Valley, compared soil loss on a grassed-backslope level terraced watershed and an unterraced watershed, both growing corn. The research included field data collected over a three-year period. Terracing reduced soil loss from 25 to 1 tons/acre/year (TAY), a 96 percent reduction.

Haith and Loehr's 1979 literature review noted the following conclusions and results:

- Terraces without water storage facilities on the less permeable soils are not as effective in controlling runoff volume (Baver et al., 1972).

- Terraces are more effective in reducing soil erosion than in reducing runoff (Stallings, 1945).

- Because terraces retain soil on the land, they substantially reduce losses of strongly adsorbed substances such as total phosphorus (Smith et al., 1978).

- Impoundment terraces, however, actually increase the loss of soluble inorganic nutrients to the groundwater below the terraced field.

Based on a literature search and personal communications, Bos (1983) compiled information on agricultural practices implemented in the Great Lakes Basin. Fact sheets for BMPs were designed to include pollutants controlled, costs, effectiveness, advantages and disadvantages. Some of the conclusions of this study were:

- Terraces were described as being highly effective in controlling erosion and reducing runoff, but their effectiveness was dependent on outlet design.

- Terraces that reduce slope length by 50 percent reduce erosion by about 20 percent.

- Relative to up and down farming, terraces reduce sediment losses by greater than 90 percent and total phosphorus losses by 75 percent.

Bos concluded that due to their high cost, it is unlikely that terraces will be constructed solely based on water quality issues. It may be more economical to change from row crops to forage to reduce pollutant. levels than to install terraces. Also, consideration must be given to the fact that terraces require engineering design and construction supervision.

In August 1983, the Nonpoint Source Control Task Force of the Water Quality Board of the International Joint Commission submitted a report to Congress which contained an evaluation of nonpoint remedial practices in the Great Lakes Basin. Terraces were among the structural practices evaluated. The following conclusions were contained in the report:

- By reducing the velocity of water runoff, pollution of waterways by suspended sediments is reduced.

- Terraces cost in the range of $30-40 per kilogram of sediment reduced.

The central theme or conclusion of many of the research reports seemed to be that terraces are a very effective means of reducing runoff, and therefore soil and nutrient losses. Their cost-effectiveness however, is questioned since a majority of the researchers concluded that it is often cheaper to change tillage or cropping patterns as compared to implementing a support practice such as terracing.

b. Factors affecting terracing effectiveness

The land slope and length of slope, and the ability of the soil to absorb moisture are the most crucial factors that influence the effectiveness of terracing (Bos, 1983). Terraces are generally used on land with a slope of up to 12 percent. Above that grade, they are still effective, but the placement of individual terraces too close together usually becomes more of a nuisance to the farmer. Crop yields are most dependent upon soil moisture. In dry areas where terraces increase the water available in the subsoil, they result in both decreased soil loss and increased yields. In areas. where water does not drain well, however, terraces may have a negative impact on yields (Haith and Loehr, 1979).

D. Grassed Waterways

Early terrace systems resulted in problems when inadequate design did not allow transport of the concentrated runoff away from the terraces. One solution which now exists is the grassed waterway. Grassed waterways are natural or constructed vegetated depressions which retain and redirect runoff water while preventing the formation of rills or gullies. They are constructed in natural field depressions or at field edges where runoff tends to concentrate. In addition to preventing gully formation, the vegetation decreases runoff by facilitating infiltration and trapping sediment particles, therefore reducing sediment delivered to receiving waters. Grassed waterways reduce erosion more than runoff volume and thus are best used in conjunction with other runoff-reducing practices such as conservation tillage and contouring.

Numerous studies have examined the effect of grassed waterways in reducing soil sediment losses; however, little quantitative data are available concerning the reduction in phosphorus losses. Other studies have estimated installation costs and subsequent operation and maintenance costs, though few studies have examined both costs and effectiveness. Table A-4 summarizes grassed waterway cost and effectiveness literature regarding the reduction of phosphorus and sediment losses. A general discussion of cost and effectiveness of grassed waterways in controlling soil erosion and phosphorus is presented below.

1. Costs of Grassed Waterways

Costs for grassed waterways are quite site specific, as size of the waterways is determined by watershed slope and acres drained. Therefore, little data is available regarding grassed waterway costs. This includes initial investment costs and increased costs associated with reduced efficiency of machinery if the waterway interferes with large machinery. A potentially more important cost is the opportunity cost of land that can no longer be planted to crops because it is part of the waterway

a. Initial investment cost

Initial investment costs include surveying the land to determine location and size of the waterway, discing of the area, eliminating gullies, installing tile drainage if needed, fertilizing, and planting grass seed. Investment costs vary depending not only on the size of the waterway but also on the amount of preparation required to eliminate gullies or other irregularities on the land designated for installation of the grassed waterway.

Table A-4. Summary of grassed waterway cost and effectiveness literature regarding reduction of phosphorus and sediment losses

Reference	Study location	Without grassed waterway: Soil loss	Without grassed waterway: Phosphorus loss	With grassed waterway: Soil loss	With grassed waterway: Phosphorus loss	Percent reduction edge of field: Soil loss	Percent reduction edge of field: Phosphorus loss	Grassed waterway costs 1/: Investment	Grassed waterway costs 1/: O&M	Cost per lb P reduced
		tons per acre per year		tons per acre per year		(%)		--------$/acre--------		
Clark, 1985	Michigan	-	-	-	-	-	-	2,200	60	-
Bos, 1983		-	-	-	-	70	50	-	-	-
International Joint Commission 1983		-	-	-	-	60-80	-	-	-	23
EPA, 1984 (Jan.)		-	-	-	-	5-40	5-40	-	-	-
Logan and Forster, 1982	NW Ohio	-	-	-	-	70	50	3,000	-	50
Lake & Morrison, 1977	Indiana	-	-	-	-	-	-	1,200	-	-
Corps of Engineers, 1983	Lake Erie	-	-	-	-	-	-	-	-	44
Humenik et al., 1982	N. Carolina	-	-	-	-	-	-	1,200	60	-
Lewis, 1985	Illinois	-	-	208 2/	-	-	-	1,197-2,098	-	-
Foster et al., 1979	W. Tennessee Watershed	34.3	-	12.9	-	62	-	-	-	-
	Piedmont Watershed	6.9	-	2.4	-	65	-	-	-	-

1/ Cost per acre of grassed waterway. One acre of grassed waterway would then serve up to 75 total acres depending on the topography of the specific site.

2/ Tons reduced per installation per year.

Few estimates are available regarding investment costs and little detail is provided in these studies regarding how the estimates were derived. Average installation costs in Illinois were broken into two segments: 1) earth-moving costs, and 2) seed, fertilizer and mulching costs. These costs, across seven different plots, ranged from $969 to $1,596 per acre for earthmoving costs, and $228 to $502 per acre in seed, fertilizer and mulching costs. Therefore, the total average installation costs were $1,197 to $2,000 per acre of grassed waterway. These costs, estimated as a statewide average by the Illinois SCS, are used for cost-sharing estimates (Lewis, 1985).

In Allen County, Indiana, installation costs were estimated to be $1,200 per acre. This cost is based on contracts awarded in Black Creek (Lake & Morrison, 1977). The SCS in North Carolina estimated grassed waterway installation costs of $1,200 per acre (Humenik et al., 1982), while the Michigan SCS estimated $2,200 per acre initial cost (Clark, 1985). Cost estimates by the Ohio SCS for northwest Ohio were as high as $3,000 per acre. For purposes of this study it was assumed, based on previous work by Logan and Forster (1982), that each waterway (1,500 feet by 30 feet) would drain an area of 75 acres.

b. Operation and maintenance costs

Operation and maintenance costs associated with grassed waterways are again quite site specific and, accordingly, are highly variable. Few estimates are available regarding total operation and maintenance costs and little detail is provided in these studies regarding how the estimates were derived.

Based on costs developed by the SCS in North Carolina, Humenik et al. (1983) estimated an annual operation and maintenance cost of 5 percent of investment cost or $60 per acre. Iowa SCS estimated 3 percent yearly operation and maintenance cost while Michigan SCS reported a $60 per acre operation and maintenance cost which is also 3 percent of the investment cost (Mussetter, 1985; Clark, 1985). In the Illinois study, the average O&M costs ranged from $196 to $344 per acre (Lewis, 1985).

c. Crop yields

Grassed waterways do not have a direct effect on per acre crop yields. However, some acreage is lost from crop production as a result of installation of grassed waterways on productive acreages. Humenik et al. (1982) estimated from 1980 SCS statistics that six percent of the cropland protected by the grassed waterway is used for the waterway itself; therefore, by this estimate, all crop inputs are potentially reduced by six percent, as is yield. Other estimates such as Logan and Forster's (1982) estimate that one acre of grassed waterway serves 75 acres of crop, and imply that crop inputs and yields are only reduced by less than two percent.

2. Effectiveness of Grassed Waterways in Reducing Nonpoint Pollution

Grassed waterways are an essential part of soil conservation on many farms. However, since grassed waterways are generally used in conjunction with other conservation practices, there are few studies that show the effectiveness of the practice itself. Furthermore, most studies concerned with grassed waterways do not estimate reductions in phosphorus losses.

Grassed waterways may be constructed on slopes ranging from 0.1 percent to greater than 5 percent on most soils (Bos, 1983). When used in conjunction with other conservation practices, they should be effective even on steep slopes (Clark et al., 1985). A discussion of the effectiveness of waterways in reducing soil and phosphorus losses is presented in the following sections.

a. Reduction in soil and phosphorus losses

In an analysis of two sample watersheds by Foster et al. (1979), it was found that grassed waterways significantly reduced sediment loss. In a Georgia Piedmont watershed, sediment was reduced from 6.9 to 2.4 tons per acre, a 65 percent reduction. A 62 percent reduction was observed in a west Tennessee watershed, reducing the sediment loss from 34.3 to 12.9 tons per acre. Although some of this reduction is due to elimination of erosion in the waterway, much of the reduction is due to deposition in the waterway (Foster et al., 1979).

The Nonpoint Source Control Task Force of the International Joint Commission concluded that grassed waterways can successfully reduce soil losses up to 60 to 80 percent in the Great Lakes Basin. This conclusion was based on various United States and Canadian watershed studies (International Joint Commission, 1983). This estimate is in agreement with a 70 percent reduction noted by Bos (1983) in which numerous Canadian publications were reviewed.

Based on reviews of the literature, some studies concluded that grassed waterways were effective in reducing phosphorus losses, while others estimated no effect on phosphorus losses. Reductions of total phosphorus losses resulting from installation of grassed waterways ranged from 5 to 50 percent (Bos, 1983; EPA, 1984). In a study prepared by the Corps of Engineers on Lake Erie, it was estimated that the cost of implementing grassed waterways for each pound of phosphorus prevented from reaching basin rivers was $44. In comparison, the International Joint Commission (1983) estimated that grassed waterways were more cost-effective with an average cost of $23 per pound of total phosphorus reduced, Logan and Forster (1982) estimated a 50 percent reduction in total phosphorus at an annual cost of $50 per pound of phosphorus reduced.

b. Factors affecting grassed waterway effectiveness

Numerous factors are responsible for determining the effectiveness of grassed waterways in controlling soil and nutrient losses. Although there are very little data available, it appears vegetation type is a main factor. As stated earlier, one erosion-reducing effect of grassed waterways is to filter sediment from runoff causing in-field deposition of eroded soil. However, without upland conservation and maintenance, waterways may become silted in and ineffective as the water flow is altered by deposition in the waterway itself.

Since most nutrients (especially phosphorus) in surface runoff are attached to the clay fraction of sediment, the usefulness of vegetation for reducing nutrient loads will depend on its ability to filter sediments from surface and shallow-channel runoff. Studies show that the sediment-trapping capability of vegetation varies with the slope and slope length before the water reaches the filter. As noted by EPA (1978), a 1974 study by Mannering and Johnson found a 54 percent reduction in sediments in a 15-mile strip of bluegrass sod. Another study of surface runoff through heavy cornstalk residue on the lower 10 feet of a 35-foot erosion plot carried only three to five percent of the sediment expected from a bare surface (EPA, 1978). Bos (1983), in a summary of several studies, recommended tall fescue grass. Tall grass slows the speed of the runoff. However, short grass in the waterway stops or traps less sediment, creates a heavier stand of grass, and causes less turbulence in the flowing water. Consequently, there would be less potential for damage to the grassed waterway (Halsey and Bolin, 1979), minimizing operation and maintenance costs.

Finally, topography is also a critical factor in determining the effectiveness of grassed waterways. Gullies should be filled and packed frequently with heavy rubber-tire equipment as earth is added. Otherwise these spots may settle and erode, reducing the effectiveness of the grassed waterway.

E. Fertilizer Management Practices

Fertilizer nutrients are lost through surface runoff, seepage through the soil profile, or conveyance off a field while being applied. The most effective practices of controlling fertilizer losses are preventive measures such as reducing either the amount of fertilizer initially applied or the vulnerability of fertilizer to runoff (Clark et al., 1985). Research of management practices relating to fertilizer application have addressed three areas: (1) rate of application, (2) method of application, and (3) timing or seasonality. Each issue will be discussed in the following sections, with summaries given of research results.

1. Rate of Application

Fertilizer application rates are recommended based on crop needs for targeted yields and the natural soil fertility. Rates may be changed in an effort to reduce costs or improve crop production. Rates applied in excess of recommended values generally produce only small increases in crop yields whereas application rates substantially less than recommended may result in losses of potential yields (Johnson and Moore, 1978). An economic analysis of phosphate fertilizer use in Ohio's Lake Erie Basin counties for corn, soybeans and wheat, shows that there is an overuse of phosphate on corn and insufficient phosphate use on soybeans. Phosphate fertilizer use on wheat is at what is considered the economic optimum (Logan and Forster, 1982).

There is a potential for a long-term increase in phosphorus losses with high phosphorus application rates. Phosphorus application greater than plant uptake will result in an accumulation of phosphorus in the soil (Johnson and Moore, 1978; Logan and Adams, 1981) unless it is lost in runoff. Research has shown that during the first year after high application rates, only 5 to 20 percent of the excess applied phosphorus actually is available for crop uptake (Simkins, 1976). The exact consequences of overfertilization, however, depends on soil characteristics, plants, and application method. The effect of fertilizer application rate on total nutrient loss may be overshadowed by the normally high losses of naturally occurring soil nutrients from row crops and small grains. The chemistry and mineralogy of a particular soil affects the extent to which phosphate fertilizer is converted to available and unavailable forms, and the distribution of phosphorus between those forms will affect the amounts of total phosphorus and available phosphorus in runoff (Logan and Adams, 1981). The relationship between phosphorus fertilization and soluble- and sediment- associated losses was well investigated by Romkens and Nelson (1974). They incorporated three rates of ordinary superphosphate in the soil profile and applied simulated rainfall. The results indicated that there was an approximately linear relationship between phosphorus addition rates and the level of soluble orthophosphate or sediment extractable (available) phosphorus in runoff.

The total phosphate load reductions that could be obtained by reducing available phosphorus in agricultural soils from 1980 levels down to sufficiency levels for corn and soybean plants to produce economically were estimated for the Lake Erie Basin. Reductions were small compared to the reductions which could be achieved with conservation tillage, but could become more significant if available phosphorus levels in basin agricultural soils continue to rise (Logan and Forster, 1982). Again, this can be explained by the fact that the natural reserves of soil nutrients are normally several times greater than amounts of applied fertilizer and tend to decrease the significance of changes in fertilizer application rates. Soluble nutrient losses, however, will usually show a greater response to changing application rates; these losses are generally very minor compared to total nutrient losses.

2. Method of Application

The method of fertilizer application affects phosphorus loss in runoff and erosion in two ways (Johnson and Moore, 1978). The first is the placement of the fertilizer and the amount of fertilizer which remains at the soil surface. Changes in nutrient content in the soil surface result in changes in the nutrient concentration in runoff and soil loss. The second involves the effect which the application method has on the soil surface condition. Altering the surface roughness may affect runoff and soil loss conditions (Johnson and Moore, 1978). Solid forms of fertilizer may be broadcast and incorporated by any of several operations. Fertilizer broadcast (thrown) onto the soil may be allowed to remain on the surface or incorporated by plowing, discing, or some form of minimum tillage. Fertilizers may also be applied in incorporated bands. Liquid fertilizers may be sprayed on the surface, injected, or incorporated with a plow, disc, or other implement.

Timmons et al. (1973) completed a two-year study of four fertilizer application practices to determine changes in runoff composition. Phosphorus (and nitrogen) losses were determined by examining the sediment and water components of surface runoff from fertilized and unfertilized plots in Minnesota. Incorporation of broadcasted fertilizer by plowing was effective in minimizing total phosphorus (and nitrogen) losses in surface runoff, since there was no significant difference in losses between this treatment and the check (no fertilizer). Fertilizer broadcast on a plowed surface was also effective in minimizing nutrient losses in surface runoff; favorable infiltration conditions caused much lower sediment and water losses from the plowed surface and this resulted in reduced nutrient losses. Incorporation of broadcasted fertilizer by discing generally resulted in phosphorus losses that were significantly higher than losses from the check treatment. Broadcasting fertilizer on a disced surface (without incorporating) generally resulted in the greatest nutrient losses in surface runoff compared to the other methods of fertilizer application.

An Iowa study observed the effect of various methods of fertilizer application on corn yields. Yields from deep band fertilizer application plots averaged 1.7 tons/ha less than from the multiple point-injection application plots. Yields from surface application plots averaged 2.5, 2.8, and 3.8 tons/ha less than yields from multiple point-injection for conventional, chisel plow, and no-till tillage practices, respectively (Prunty, 1985).

3. Timing of Application

The timing or season of fertilizer application is determined by the type of fertilizer, crop, soil characteristics, and scheduling of other farm operations. The season in which fertilizer is applied affects the amounts of runoff and soil loss available as a transport mechanism. Fertilizer applied in the fall will be subject to the high volumes of runoff resulting from the following spring's snowmelt. Soluble phosphorus losses from fertilizer applied in the fall were estimated to be 6 to 9 percent greater with row crops, and about 20 percent greater with small grains, when compared to spring-applied fertilizer. However, since most sediment-associated losses do not originate from fertilizer nutrients, the relationship of sediment-associated losses to application rate will probably not be significantly affected by the season of application (Johnson and Moore, 1978).

Burwell et al. (1975) concluded that delaying spring fertilizer application, or part of the application, in most cases would only slightly reduce average annual soluble phosphorus losses. Soluble phosphorus losses during this period comprise about 45 percent of the annual soluble losses.

4. Problems Encountered in Previous Research

Several factors make it difficult to estimate the impact of management practices on phosphorus losses. The basic problem is that the total phosphorus content of soils ranges from 0.01 to 0.13 percent (ARS, 1975), and small changes in these values resulting from different management practices are difficult to measure. Second, when evaluating nutrient losses in surface runoff, it is necessary to measure both the nutrient concentration in the sediment and runoff water, and the quantities of sediment and water in the runoff. Failure to do so could cause an erroneous conclusion, since it is possible for runoff to have high nutrient concentrations and yet contribute low nutrient losses because of low sediment and water losses (Timmons et al., 1973).

5. Conclusions

Good management means fertilizing according to reliable soil tests, making applications at the optimum times, and using the best fertilization methods along with alternatives or supplements to fertilizers.

Fertilizer management offers the advantages of maximizing returns and optimizing input costs, and its low cost makes it a potentially cost-effective BMP. Fertilizer management, however, may require extra time and effort to have soils sampled and fertilizer specially mixed, as well as the possibility of increased costs associated with split applications (International Joint Commission, 1983).

F. Sediment Basins

Sediment basins are catchments designed to impound agricultural runoff water long enough for suspended sediment and absorbed nutrients to settle out. These ponds or basins can be constructed along a stream or between a field and a waterway. Unlike BMPs such as terracing and contouring that attempt to reduce sediment and nutrient loses, this sediment reduction method is designed to collect and reduce pollutants after they leave a field, but before they can cause environmental damage. These basins have the added advantage that they can reduce flooding peaks and decrease downstream erosion. They can provide an additional water source for livestock, and the material which is periodically dredged from the basins is high quality topsoil which can be used to fill and cover areas in need of topsoil replenishment. Cited disadvantages include: (1) regular maintenance requirements; (2) uneconomical to design for fine particle removal; (3) fine particles which adsorb most chemicals and nutrients are not controlled; (4) unused or low valued land must be used for placement--otherwise, some land would need to be taken out of production or possibly easements obtained; and (5) failure to address the source of sedimentation (Bos, 1983; International Joint Commission, 1983).

The remainder of this subsection is divided in two parts with the first discussing the cost of this BMP and the second examining its efficiency in removing suspended soil particles and phosphorus.

1. Costs of Sediment Basins

The cost of constructing and maintaining sediment basins is often cited as their major disadvantage. Sediment basin size is a major cost-determining factor and is dependent on several variables including frequency and intensity of rainfall, the area drained, soil type and topography. Sediment basin site is usually expressed in terms of the area drained. Based on conversations with SCS engineers in Region V (Minnesota, Wisconsin, Michigan, Illinois, Indiana and Ohio), typical basins in this region drain from 3 to 21 acres with most basins serving from 5 to 10 acres. Construction costs include earthwork and outlet construction, and range from $1,000 to $1,500 per structure for basins draining 5 to 10 acres. Basins draining 15 to 20 acres cost approximately $2,500 to $3,000 to build.

Annual costs are about 8 to 10 percent of the construction cost. Maintenance activities include mowing vegetative cover in and around the basin and periodically cleaning out material that has accumulated in the basin. This latter activity is important for maintaining the basin's suspended solids removal efficiency. The number of times a basin needs cleaning depends on the amount of rainfall and the number of major storms. Basins may need cleaning several times per year or several years may elapse before dredging is necessary. A typical timeframe is one cleaning every one to three years.

The expected lifetime of a sediment basin is ten years, but this period can be extended with more frequent sediment removal.

2. Effectiveness of Sediment Basins

Because the design (shape, size, depth, etc.) is important in determining the sediment removal efficiency of a sediment basin, the desired effectiveness of a basin becomes a design criterion. The design effectiveness of a basin depends on the volume of water it can store relative to the volume which flows through it during a storm. The greater the storage volume relative to inflow, the greater the basin's effectiveness. Unfortunately, construction costs also become higher as a basin's effectiveness increases; thus, a compromise between these two factors must be made.

Sediment removal efficiencies typically range from 60 to 95 percent (Dendy, 1974; Robbins and Carter, 1975; Brown et al., 1981; Bos, 1983). SCS personnel indicated sediment efficiency of 90 to 100 percent when basins are properly constructed and maintained. This is confirmed by the Robbins and Carter (1975) and Dendy (1974) studies. In the latter study, 17 flood-retarding reservoirs scattered throughout the U.S. were examined. Sediment trap efficiencies of 81 to 98 percent were found.

The major factors (other than basin design) controlling sediment removal are the flow rate and the sediment concentration of the water entering a basin. A recent five-year study conducted by Brown et al. (1981), examining the sediment removal of a sediment basin, demonstrates the influence of these factors. They found a typical removal rate of 65 to 76 percent of sediment. However, when the flow rate into the pond was 28 to 170 liters/set (L/S), the peak sediment removal efficiency was 68 percent or less. Sediment removal efficiency increased to 83 percent as the flow into the basin increased from 340 to 453 L/S. The removal efficiency dropped, however, to 75 percent at flows above this because water was flowing too quickly through the pond to allow proper sediment settling i.e., at 623 to 765 L/S retention time dropped by almost an hour.

Removal of total phosphorus by a sediment basin is lower than sediment removal levels because:

- Phosphorus is present in both soluble and insoluble forms; the former generally passes through a pond even when there is 100 percent sediment removal (Brown et al., 1981).

- Phosphorus tends to bind to smaller clay particles which do not readily settle out, particularly when flow rate is not optimal for particle settling (Brown et al., 1981).

Bos (1983) and Clark et al. (1985) report total phosphorus removal levels of 40 to 50 percent. The Brown et al. (1981) five-year study of a sediment basin reported removal levels of 25 to 33 percent.

Sediment basins can also help remove non-persistent pesticides which are attached to soil particles, because these basins provide time for these chemicals to break down before entering receiving waterways (Bos, 1983). Unfortunately, many such chemicals adhere to the smaller soil particles which are less effectively retained by sediment basins (Bos, 1983; International Joint Commission, 1983).

G. Livestock Exclusions

Limiting access by livestock to an open watercourse may be very effective in reducing nonpoint phosphorus loadings. Livestock exclusions (stream-bank fencing) are effective in reducing phosphorus loadings in two ways: (1) by eliminating fecal deposits from entering surface water directly and (2) by reducing the disturbance of stream bank and bottom sediments due to trampling by livestock.

Very few studies have been conducted regarding the effectiveness of livestock exclusions in reducing phosphorus loadings to surface waters, especially streams; this is at least partly a consequence of the great variability of implementation costs and resulting phosphorus load reductions. Currently, a relatively large livestock exclusion study has been undertaken in Florida as part of the Rural Clean Water Program (RCWP); however, results from this project are not currently available. Nevertheless, some estimates of costs and effectiveness of livestock, exclusions are available and are discussed below.

1. Costs of Livestock Exclusions

Variations in costs for implementing livestock exclusion BMPs may be substantial depending on site specific characteristics. For example, if a stream passes through the middle of a pasture, fencing will be required on both sides of the stream. In other cases, a stream may flow adjacent to the boundary of a pasture, thus requiring fencing on only one side.

Fencing investment costs, as estimated by the Ohio Soil Conservation Service are $2,100 per mile (Hemmer, 1985); Illinois SCS cost estimates are $2,394 per mile (Lewis, 1985). Both cost estimates are for four wire fences. Annual costs are estimated to be 5 percent of investment costs and the fence life span was estimated to be 20 and 25 years by the Illinois and Ohio SCS, respectively.

Other variations in the costs of livestock exclusions are associated with providing an alternative water supply for the livestock, if necessary. In the Florida livestock exclusion RCWP, ponds were dug that were relatively inexpensive since the water table is very high in this area (Ritter, 1985). Frequently, the need for an alternate water supply will require pumping, piping and holding tanks for which costs can be extremely variable.

In other cases, provision of concrete or gravel access ramps or crossings in controlled areas are suitable for water supply; access ramps are estimated to range in cost from $250 to $500 each, with two ramps normally required (Bos, 1983). Annual costs associated with the access ramps are expected to be five percent of the original investment costs.

In addition to the costs associated with fencing and provision of an alternate water supply, there are generally costs associated with loss of grazing land due to the fencing. These costs depend on the topography of the stream to be fenced; in general, the more a stream deviates from a straight course, the larger the area of grazing land lost due to the exclusion. In some instances use of filter strips (a strip of land, the vegetation on which filters sediment and nutrients from runoff) is also recommended in conjunction with livestock exclusions. Estimates of the magnitude of these costs are not available.

2. Effectiveness of Livestock Exclusions in Reducing Nonpoint Pollution

In addition to reducing the chances of direct livestock fecal deposits in a stream, exclusion structures limit phosphorus loadings to surface water by reducing sedimentation. As livestock trample the stream banks and bottoms, sediment is stirred up and migrates downstream.

Phosphorus loadings are estimated to be reduced by 30 percent due to exclusions; unfortunately, few test results are available. However, the magnitude of the decrease in phosphorus loadings will depend largely on site-specific conditions such as soil stability, intensity of livestock use and ability of the watercourse to assimilate the contaminants (Bos, 1983).

H. Feedlot Runoff Waste Management

The potential of stormwater runoff from livestock feedlots polluting adjacent water bodies has been documented (Sutton et al., 1976; Vanderholm et al., 1979; Young et al., 1980). As a result, several technologies capable of controlling feedlot runoff have been studied in considerable detail.

Essentially there are two principal types of feedlot runoff control systems discussed in the literature: (1) a system which collects all of the runoff, detains it in storage and subsequently applies it to cropland (denoted here as a zero discharge system), and (2) a system which collects all runoff, settles out particulates and provides vegetated strips for filtration to further clarify the effluent (denoted here as a vegetative filter system). Of course, depending on site-specific conditions, there are numerous variations in the systems which can be implemented. Typically both systems divert clean water runoff which would enter the feedlot.

In an effort to reduce pollution from large feedlot operations, EPA promulgated certain regulations pertaining to runoff control requirements. The regulations require a permit for all livestock facilities over 1000 animal units (beef animal or equivalent) with point source discharges of pollutants into navigable waters. Facilities with 300 to 1,000 animal units require an operating permit (White and Forster, 1978). As a consequence of this, numerous studies have been undertaken examining the costs of the different control systems. Other studies estimated reductions in various pollutants, including phosphorus, resulting from the implementation of various runoff control systems. A summary of the major studies is presented in Table A-5. A general discussion of cost and effectiveness of feedlot runoff control systems is presented below.

1. Costs of Feedlot Runoff Controls

Feedlot runoff control costs are dependent on feedlot size, type of runoff control system, annual rainfall and site-specific conditions such as topography and feedlot design. Accordingly, cost ranges (both investment and operation and maintenance) are very broad, as illustrated in published studies of runoff control systems. For purposes of this analysis, cost estimates for each of the major control systems (zero discharge and vegetative filter) are discussed separately.

a. Initial investment cost

Investment costs for a zero discharge runoff control system in Minnesota were estimated to range from $1,439 to $9,493 for beef feedlots ranging in size from 100 to 1,500 head, respectively. These costs were estimated for a "typical" feedlot, and included expenditures for a diversion terrace to keep unpolluted water off the lot, a settling basin, a detention pond and sufficient pumping equipment to apply the runoff to irrigated fields (Pherson, 1974). A similar system installed on a dairy fan was estimated to require investment outlays of $2,747 and $3,725 for 80 and 150 head

Table A-5. Summary of feedlot waste management cost and effectiveness literature regarding the reduction of phosphorus and sediment in runoff

Reference	Study location	Type of operation	Size of operation	Type of waste management	Baseline Solids loss	Baseline Phosphorus loss	Control Solids loss	Control Phosphorus loss	Percent reduction Solids loss	Percent reduction Phosphorus loss	Runoff control costs Investment	Runoff control costs Annual
			(head)		----pounds per year----						----dollars----	
Vanderholm et al. 1979	Illinois	Dairy	100	Vegetative Filter	19,993	347	906	12.7	96	96	6,746	844
		Beef Feedlot	500	Vegetative Filter					-	>70	7,920	874
		Beef Feedlot	500	Vegetative Filter	9,283	-	863	-	91	-	8,960	958
		Dairy	100	Zero Discharge	-	-	-	-	-	-	8,103	1,111
		Beef Feedlot	500	Zero Discharge	-	-	-	-	-	-	10,725	1,333
		Beef Feedlot	500	Zero Discharge	-	-	-	-	-	-	9,823	1,656
Young et al. 1980	Minnesota	Beef Feedlot	310	Vegetative Filter					79	83		
Sutton et al. 1976	Indiana	Swine Feedlot	1,000	Vegetative Filter					68 3/	92	3,000	
Buxton and Ziegler, 1974	Northern U.S.	Dairy	80	Zero Discharge							2,747	
		Dairy	150								3,725	
Pherson, 1974	Minnesota	Beef Feedlot	100	Zero Discharge							1,439	198
			500								6,287	614
			1,000								7,890	761
			1,500								9,493	911
Johnson and Davis, 1975	-	Beef Feedlot	<100	Zero Discharge							145.20 1/	21.17 1/
			100-199								21.00 1/	3.19 1/
			200-499								11.60 1/	1.84 1/
			500-999								8.18 1/	1.28 1/
			>1000								3.13 1/	0.69 1/
Miner et al. 2/ 1979	Ames, IA	Beef Feedlot	200	Zero Discharge							4,582	908
			2,000								16,820	3,260
			20,000								131,800	25,600
	Astoria, OR		200								7,586	1,494
			2,000								46,160	9,060
			20,000								463,000	90,000
	Bozeman, MT		200								4,162	822
			2,000								13,400	2,540
			20,000								98,200	18,400
	Corvallis, OR		200								5,116	1,012
			2,000								22,240	4,300
			20,000								193,000	37,600
	Experiment, GA		200								4,680	946
			2,000								17,380	3,660
			20,000								163,200	33,400
	Lubbock, TX		200								4,370	858
			2,000								15,040	2,840
			20,000								113,600	21,200
	Pendleton, OR		200								3,548	696
			2,000								7,300	1,400
			20,000								36,800	7,000

(continued)...

Table A-5. (continued)

Reference	Study location	Type of operation	Size of operation	Type of waste management	Baseline		Control		Percent reduction		Runoff control costs	
					Solids loss	Phosphorus loss	Solids loss	Phosphorus loss	Solids loss	Phosphorus loss	Investment	Annual
			(head)		---pounds---						---dollars---	
Madden and Dornbush, 1971	South Dakota	Beef Feedlot	2,000			3,500		1,890		46		
		Dairy	45			125		83		34		
		Beef Feedlot	420			1,900		800		58		
		Beef Feedlot	320			98		70		28		
Butler, et al. 1974				Vegetative Filter						64		

1/ Costs represent per head costs.

2/ Annual costs include interest and depreciation.

3/ Solids loss reduction from settling basin only.

facilities, respectively (Buxton and Ziegler, 1974). Johnson and Davis (1975) found that investment costs for a zero discharge system were highly dependent on facility size. In beef feedlots with a capacity of less than 100 head, per head costs were estimated to be $145. Investment costs per head for lots with capacities from 100 to 199 head were only $21; investment costs were $18 per head for facilities with more than 1,000 head. Large differences in investment cost per head were also estimated by White and Forster (1978) with costs ranging from nearly $23 per head for a paved cattle feedlot with a 100-head capacity to only $7 per head for an unpaved feedlot with a 700-head capacity.

In a detailed study of zero discharge runoff control system costs, computer models were developed to determine optimal design characteristics. Climatic conditions (e.g., rainfall patterns and temperature) were very important in determining design characteristics and corresponding system costs; essentially, areas with high rainfall and/or low temperatures had correspondingly higher system investment costs. Investment costs for a 200-head capacity beef feedlot were estimated to range from approximately $3,500 in Pendleton, Oregon to $7,600 in Astoria, Oregon (Miner et al., 1979).

In an Illinois study comparing the costs of the zero discharge and vegetative filter systems, actual investment *costs* for zero discharge systems Installed in beef feedlots were approximately $9,800 to $10,700 for 500-head capacity facilities. Investment costs for a 100-head dairy were $8,100. Vegetative filter systems were somewhat less expensive to install, with actual costs varying from approximately $7,900 to $9,000 for a 500-head beef feedlot while costs for a 100-head dairy were only $6,700 (Vanderholm et al., 1979).

b. Operation and maintenance costs

Annual costs for operating zero discharge feedlot runoff control systems are primarily associated with pumping costs, equipment repair and labor.

These costs were estimated to range from $198 to $911 for beef feedlots with capacities of 100 to 1,500 head (Pherson, 1974). Annual costs as estimated by Johnson and Davis (1975) are very comparable to Pherson, with the exception of the smaller feedlots (less than 500-head capacity) where Johnson and Davis estimate somewhat higher costs.

Estimation of annual operating costs by Miner et al. (1979) included both operating and ownership costs. These costs were grouped into the following categories: (1) interest and depreciation; (2) repair and maintenance; (3) taxes; (4) insurance; (5) labor; and (6) energy. Because these estimates also include ownership costs (i.e., interest and depreciation), they are somewhat high.

In an annual cost comparison of zero discharge and vegetative filter systems, the vegetative filter systems were estimated to cost from 20 to 40 percent less than the zero discharge system (Vanderholm, 1979). Unfortunately, few details were provided regarding the estimation of these costs.

2. Effectiveness of Feedlot Runoff Waste Management in Reducing Nonpoint Pollution

Installation of zero discharge or vegetative filter systems to control feedlot runoff is believed to be an effective measure for controlling phosphorus and other pollutants. Unfortunately, quantitative measures of performance, especially for the zero discharge system, are quite limited. In an analysis of runoff wastes from commercial feedlots in South Dakota, Madden and Dornbush (1971) measured changes in runoff wastes from installing diversions and settling basins. (Diversions, which prohibit unpolluted stormwater from entering the feedlot wastes and settling basins are both components in the zero discharge and vegetative filter systems.) Results indicated reductions in phosphorus losses ranging from approximately 30 to 60 percent. In this analysis, phosphorus losses before the system was in place were estimated to range from 3,500 pounds per year for a 2,000-head beef feedlot to approximately 100 pounds per year for a 320-head beef feedlot. Differences in phosphorus runoff (not attributed to feedlot size) depended on rainfall and snowmelt runoff patterns and individual feedlot characteristics.

Vegetative filters were found to reduce solids and phosphorus losses due to runoff by 79 and 83 percent, respectively, in a Minnesota study (Young et al., 1980). Results from a vegetative filter system installed on a swine feedlot in Indiana indicated reductions in solids loss of 68 percent while phosphorus losses were reduced 92 percent (Sutton et al., 1976). Vegetative filter systems reduced solids losses by over 90 percent from a beef feedlot and a dairy in Illinois. Reductions in phosphorus losses were somewhat more variable, ranging from over 70 percent to 96 percent (Vanderholm et al., 1979).

APPENDIX B

POTW Case Studies

Exhibit B-1. Tipton, Indiana Case

POTW Size Daily: Annual:	1.17 MGD 379 MG
Secondary POTW Treatment Technology:	Activated Sludge
Advanced Secondary Phosphorus Removal Technology:	Chemical addition (ferric chloride)
Capital Cost Total: Phosphorus:	$6,088,100 ($1985) $ 250,000 ($1985)
Annual Operation and Maintenance Total: Phosphorus: 1/	$ 197,304 ($1985) $ 9,000 ($1985)
Phosphorus Influent: Effluent:	3.00 mg/l .44 mg/l
Removal Efficiency:	85 percent
Annual Cost Calculations:	
Capital Recovery Factor at 20 years and 10 percent interest =	.1175
Capital Cost Phosphorus X CRF =	Annual Capital Cost
$250,000 X .1175 =	$29,375
Annual Capital Cost + Annual Operation and Maintenance Cost =	Annual Treatment Cost
$29,375 + $9,000 =	$38,375
Phosphorus Removal Calculations:	
Influent - Effluent = 3.0 mg/l - .44 mg/l =	Load Removed 2.56 mg/l
2.56 mg/l X 8.34 X 1.17 MGD X 365=	8,092 lbs/yr
Cost-Effectiveness Calculations:	
$\frac{\$38,375/yr}{8092\ lbs/yr}$ =	$4.74/lb

1/ Phosphorus removal cost components requested were equipment, labor, energy, supplies and sludge handling and removal costs. The estimates obtained did not specify costs by line item.

Exhibit B-2. Ionia, Michigan Case

POTW Size Daily:	1.6 MGD
Annual:	584 MG
Secondary POTW Treatment Technology:	Rotary biological discs
Advanced Secondary Phosphorus Removal Technology:	Chemical addition (aluminum sulfate & polymers)
Capital Cost Total: 1/	$7,073,078 ($1985)
- Phosphorus: 2/	$235,455 ($1985)
Annual Operation and Maintenance Total:	$300,000 ($1985)
Phosphorus: 3/	$33,500 ($1985)
Phosphorus Influent:	3.6 mg/l
Effluent:	.9 mg/l
Removal Efficiency:	75 percent

Annual Cost Calculations:

Capital Recovery Factor at 20 years and 10 percent interest =	.1175
Capital Cost Phosphorus X CRF =	Annual Capital Cost
$235,455 X .1175 =	$27,666
Annual Capital Cost + Annual Operation and Maintenance Cost =	Annual Treatment Cost
$27,666 + $33,500 =	$61,166

Phosphorus Removal Calculations:

Influent - Effluent =	Load Removed
3.6 mg/l - .9 mg/l =	2.7 mg/l
2.7 mg/l X 8.34 X 1.6 MGD X 365 =	13,151 lbs/yr

Cost-Effectiveness Calculations:

$$\frac{\$61,166/yr}{13,151 \text{ lbs/yr}} = \$4.65/1b$$

1/ $3,755,000 in 1975.
2/ $125,000 in 1975.
3/ Phosphorus removal cost components requested were equipment, labor, energy, supplies and sludge handling and removal costs. The estimates obtained only specified chemicals, maintenance and labor costs by line item.

Exhibit B-3. Owosso, Michigan Case

POTW Size Daily:	4.5 MGD
Annual:	1642.5 MG
Secondary POTW Treatment Technology:	Chemical treatment & filtration
Advanced Secondary Phosphorus Removal Technology:	Chemical addition (iron & polymer)
Capital Cost Total:	$12,000,000 ($1985)
Phosphorus:	$150,000 ($1985)
Annual Operation and Maintenance Total:	$1,800,000 ($1985)
Phosphorus: 1/	$70,000 to 75,000 ($1985)
Phosphorus Influent:	5 mg/l to 6 mg/l
Effluent:	.4 mg/l to .5 mg/l
Removal Efficiency:	90 to 93 percent

Annual Cost Calculations:

Capital Recovery Factor at 20 years and 10 percent interest =	.1175
Capital Cost Phosphorus X CRF =	Annual Capital Cost
$150,000 x .1175 =	$17,625
Annual Capital Cost + Annual Operation and Maintenance Cost =	Annual Treatment Cost
$17,625 + $70,000 =	$87,625
$17,625 + $75,000 =	$92,625

Phosphorus Removal Calculations:

Influent - Effluent =	Load Removed
5 mg/l - .4 mg/l =	4.6 mg/l
5 mg/l - .5 mg/l =	4.5 mg/l
6 mg/l - .5 mg/l =	5.5 mg/l
6 mg/l - .4 mg/l =	5.6 mg/l
4.6 mg/l X 8.34 X 4.5 MGD X 365 =	63,013 lbs/yr
4.5 mg/l X 8.34 X 4.5 MGD X 365 =	61,643 lbs/yr
5.5 mg/l X 8.34 X 4.5 MGD X 365 =	75,341 lbs/yr
5.6 mg/l X 8.34 X 4.5 MGD X 365 =	76,711 lbs/yr

Range: 61,643 lbs to 76,711 lbs

1/ Phosphorus removal cost components requested were equipment, labor, energy, supplies and sludge handling and removal costs. The estimates obtained did not specify costs by line item.

Cost-Effectiveness Calculations:

$\frac{\$87,625/yr}{61,643\ lbs/yr} =$ $1.42/lb

$\frac{\$87,625/yr}{76,711\ lbs/yr} =$ $1.14/lb

$\frac{\$92,625/yr}{61,643\ lbs/yr} =$ $1.50/lb

$\frac{\$92,625/yr}{76,711\ lbs/yr} =$ $1.21/lb

Range from $1.14/lb to $1.50/lb

Exhibit B-4. Aurora, Minnesota Case

POTW Size Daily:	.44 MGD
Annual:	162 MG
Secondary POTW Treatment Technology:	Extended Aeration With Tertiary Filters
Advanced Secondary Phosphorus Removal Technology:	Chemical addition (aluminum sulfate)
Capital Cost Total:	$2,200,000 ($1985)
Phosphorus:	$220,000 ($1985)
Annual Operation and Maintenance Total:	$180,000 ($1985)
Phosphorus: 1/	$2,660 ($1985)
Phosphorus Influent:	2.8 mg/l - 4.0 mg/l
Effluent:	.8 mg/l
Removal Efficiency:	71 to 80 percent

Annual Cost Calculations:

Capital Recovery Factor at 20 years and 10 percent interest=	.1175
Capital Cost Phosphorus X CRF =	Annual Capital Cost
$220,000 x .1175 =	$25,850
Annual Capital Cost + Annual Operation and Maintenance Cost =	Annual Treatment Cost
$25,850 + $2,660 =	$28,510

Phosphorus Removal Calculations:

Influent - Effluent =	Load Removed
2.8 mg/l - .8 mg/l =	2.0 mg/l
4.0 mg/l - .8 mg/l =	3.2 mg/l
2.0 mg/l X 8.34 X 0.44 MGD X 365 =	2,702 lbs/yr
3.2 mg/l X 8.34 X 0.44 MGD X 365 =	4,323 lbs/yr

Cost-Effectiveness Calculations:

$\frac{\$28,510/yr}{2,702 \text{ lbs/yr}}$ =	$10.55/lb
$\frac{\$28,510/yr}{4,323 \text{ lbs/yr}}$ =	$6.60/lb

1/ Chemicals, maintenance and energy costs were specific line items included. Other phosphorus removal costs (e.g., sludge handling, equipment and labor) were not specified.

Exhibit B-5. Bemidji, Minnesota Case

POTW Size Daily:	1.1 MGD
Annual:	401.5 MG
Secondary POTW Treatment Technology:	Activated Sludge
Advanced Secondary Phosphorus Removal Technology,:	Chemical addition (aluminum sulfate & polymer)
Capital Cost Total-:	$14,000,000 ($1985)
Phosphorus: 1/	$491,480 ($1985)
Annual Operation and Maintenance Total: 2/	$719,474 ($1985)
Phosphorus: 3/	$82,000 ($1985)
Phosphorus Influent:	3 mg/l to 8 mg/l
Effluent:	0.1 mg/l
Removal Efficiency:	97 to 99 percent

Annual Cost Calculations:

Capital Recovery Factor at 20 years and 10 percent interest =	.1175
Capital Cost Phosphorus X CRF =	Annual Capital Cost
$491,480 X .1175 =	$57,749
Annual Capital Cost + Annual Operation and Maintenance Cost =	Annual Treatment Cost
$57,749 + $82,000 =	$139,749

Phosphorus Removal Calculations:

Influent - Effluent =	Load Removed
3.0 mg/l - .1 mg/l =	2.9 mg/l
8.0 mg/l - .1 mg/l =	7.9 mg/l
2.9 mg/l X 8.34 X 1.1 MGD X 365 =	9,711 lbs/yr
7.9 mg/l X 8.34 X 1.1 MGD X 365 =	26,453 lbs/yr

Cost-Effectfveness Calculations:

$\frac{\$139,749/yr}{9,711\ lbs/yr}$ = $14.39/lb

$\frac{\$139,749/yr}{26,453\ lbs/yr}$ = $5.28/lb

1/ Preliminary construction cost estimate in 1982 was $440,000.
2/ 1986 budget estimate.
3/ Phosphorus removal cost components requested were equipment, labor, energy, supplies and sludge handling and removal costs. The estimates obtained did not specify costs by line item.

Exhibit B-6. Eveleth, Minnesota Case

POTW Size Daily:	.7 MGD
Annual:	225.5 MG
Secondary POTW Treatment Technology:	Activated Sludge
Advanced Secondary Phosphorus Removal Technology:	Chemical addition (alum)
Capital Cost Total:	$5,000,000 ($1985)
Phosphorus:	$20,000 ($1985)
Annual Operation and Maintenance Total:	$115,000 ($1985)
Phosphorus: 1/	$3,520 ($1985)
Phosphorus Influent:	3.0 mg/l
Effluent:	.7 mg/l to .8 mg/l
Removal Efficiency:	73 to 77 percent

Annual Cost Calculations:

Capital Recovery Factor at 20 years and 10 percent interest =	.1175
Capital Cost Phosphorus X CRF =	Annual Capital Cost
$20,000 x .1175 =	$2,350
Annual Capital Cost + Annual Operation and Maintenance Cost =	Annual Treatment Cost
$2,350 + $3,520 =	$5,870

Phosphorus Removal Calculations:

Influent - Effluent =	Load Removed
3.0 mg/l - .7 mg/l =	2.30 mg/l
3.0 mg/l - .8 mg/l =	2.20 mg/l
2.3 mg/l X 8.34 lb/MG X 225.5 MG =	4,328 lbs/yr
2.2 mg/l X 8.34 lb/MG X 225.5 MG =	4,137 lbs/yr

Cost-Effectiveness Calculations:

$\frac{\$5,870/yr}{4,326 \text{ lbs/yr}}$ =	$1.36/lb
$\frac{\$5,870/yr}{4,137 \text{ lbs/yr}}$ =	$1.42/1b

1 Phosphorus removal cost components requested were equipment, labor, energy, supplies and sludge handling and removal costs. The estimates. obtained only specified energy and chemical costs by line item.

Exhibit B-7. Fergus Falls, Minnesota Case

POTW Size Daily: Annual:	1.6 MGD 582 MG
Secondary POTW Treatment Technology:	Extended Aeration
Advanced Secondary Phosphorus Removal Technology:	Chemical Addition (ferric chloride)
Capital Cost Total: Phosphorus:	\$9,000,000 (\$1985) \$ 150,000 (\$1985)
Annual Operation and Maintenance Total: - Phosphorus: 1/	\$ 430,000 (\$1985) \$ 60,225 (\$1985)
Phosphorus Influent: 2/ Effluent:	10.00 mg/l - 14.00 mg/l .9 mg/l
Removal Efficiency:	91 to 94 percent

Annual Cost Calculations:

Capital Recovery Factor at 20 years and 10 percent interest =	.1175
Capital Cost Phosphorus X CRF =	Annual Capital Cost
\$150,000 x .1175 =	\$17,625
Annual Capital Cost + Annual Operation and Maintenance Cost =	Annual Treatment Cost
\$17,625 + \$60,225 =	\$77,850

Phosphorus Removal Calculations:

Influent - Effluent =	Load Removed
14.0 mg/l - .9 mg/l =	13.10 mg/l
10.0 mg/l - .9 mg/l =	9.10 mg/l
13.10 mg/l X 8.34 X 1.16 MGD X 365 =	63,586 lbs/yr
9.10 mg/l X 8.34 X 1.16 MGD X 365 =	44,170 lbs/yr

Cost-Effectiveness Calculations:

$$\frac{\$77,850/\text{yr}}{63,586 \text{ lbs/yr}} = \$1.22/\text{lb}$$

$$\frac{\$77,850/\text{yr}}{44,170 \text{ lbs/yr}} = \$1.76/\text{lb}$$

1/ Phosphorus removal cost components requested were edquipment labor, energy, supplies and sludge handling and removal costs. The estimates obtained did not specify costs by line item.

2/ Phosphorus ranges from 25 mg/l to 5 mg/l with an average of 14 mg/l. Once the facility is in full operation the expected influent is 10 mg/l. The excess loadings are caused by a nearby cheese manufacturing plant.

Exhibit B-8. Gilbert, Minnesota Case

POTW Size Daily:	.4 MGD
Annual:	146 MG
Secondary POTW Treatment Technology:	Extended Aeration with Tertiary Filters
Advanced Secondary Phosphorus Removal Technology:	Chemical addition (aluminum sulfate)
Capital Cost Total:	$2,346,091 ($1985)
Phosphorus: (10%)	$ 234,609 ($1985)
Annual Operation and Maintenance Total:	$ 187,000 ($1985)
Phosphorus: 1/	$ 2,500 ($1985)
Phosphorus Influent:	2 mg/l
Effluent:	.8 mg/l
Removal Efficiency:	60 percent

Annual Cost Calculations:

Capital Recovery Factor at 20 years and 10 percent interest =	.1175
Capital Cost Phosphorus X CRF =	Annual Capital Cost
$234,609 X .1175 =	$27,567
Annual Capital Cost + Annual Operation and Maintenance Cost =	Annual Treatment Cost
$27,567 + $2,500 =	$30,067

Phosphorus Removal Calculations:

Influent - Effluent =	Load Removed
2.0 mg/l - .8 mg/l =	1.20 mg/l
1.20 mg/l X 8.34 X 0.4 MGD X 365=	1,461 lbs/yr

Cost-Effectiveness Calculations:

$\frac{\$30,067/yr}{1461\ lbs/yr}$ =	$20.58/lb

1/ Phosphorus removal cost components requested were equipment, labor, energy, supplies and sludge handling and removal costs. The estimates obtained did not specify costs by line item.

Exhibit B-9. Pine Island, Minnesota Case

POTW Size Daily: Annual:	.3 MGD 108 MG
Secondary POTW Treatment Technology:	Activated Sludge
Advanced Secondary Phosphorus Removal Technology:	Chemical addition (pickle liquor)
Capital Cost Total: Phosphorus:	$1,700,000 ($1985) $352,000 ($1985)
Annual Operation and Maintenance Total: Phosphorus: 1/	$132,442 ($1985) $7,722 ($1985)
Phosphorus Influent: Effluent:	6.0 mg/l - 10.0 mg/l 1.0 mg/l
Removal Efficiency:	83 to 90 percent

Annual Cost Calculations:

Capital Recovery Factor at 20 years and 10 percent interest =	.1175
Capital Cost Phosphorus X CRF =	Annual Capital Cost
$352,000 X .1175 =	$41,360
Annual Capital Cost + Annual Operation and Maintenance Cost =	Annual Treatment Cost
$41,360 + $7,722 =	$49,082

Phosphorus Removal Calculations:

Influent - Effluent =	Load Removed
6.0 mg/l - 1.0 mg/l =	5.0 mg/l
10.0 mg/l - 1.0 mg/l =	9.0 mg/l
5.0 mg/l X 8.34 X 0.3 MGD X 365=	4,504 lbs/yr
9.0 mg/l X 8.34 X 0.3 MGD X 365=	8,106 lbs/yr

*Cost-Effectiveness Calculations:

$\frac{\$49,082/yr}{4,504\ lbs/yr}$ =	$10.90/lb
$\frac{\$49,082/yr}{8,106\ lbs/yr}$ =	$6.06/lb

1/ Pickle liquor is free, except for transportation costs. Five percent of total O&M is used to determine labor, maintenance and energy costs associated with P removal. Additional $1,000-1,200/yr for sludge handling costs.

Exhibit B-10. Rochester, Minnesota Case

POTW Size Daily:	10 MGD
Annual:	3650 MG
Secondary POTW Treatment Technology:	Activated Sludge
Advanced Secondary Phosphorus Removal Technology:	PhoStrip 1/
Capital Cost Total:	$56,000,000 ($1985)
Phosphorus:	$ 3,500,000 ($1985)
Annual Operation and Maintenance Total:	$ 3,400,000 ($1985)
Phosphorus: 3/	$ 450,000 ($1985)
Phosphorus Influent:	14.0 mg/l
Effluent: 3/	1.0 mg/l
Removal Efficiency:	93 percent

Annual Cost Calculations:

Capital Recovery Factor at 20 years and 10 percent interest =	.1175
Capital Cost Phosphorus X CRF =	Annual Capital Cost
$3,500,000 x .1175 =	$411,250
Annual Capital Cost + Annual Operation and Maintenance Cost =	Annual Treatment Cost
$411,250 + $450,000 =	$861,250

Phosphorus Removal Calculations:

Influent - Effluent =	Load Removed
14.0 mg/l - 1.0 mg/l =	13.0 mg/l
13.0 mg/l X 8.34 X 10.00 MGD X 365 =	395,733 lbs/yr

Cost-Effectiveness Calculations:

$861,250/yr = 395,733 lbs/yr	$2.18/lb

1/ PhoStrip is a combination of biological and chemical processes; the chemicals used are lime and alum.

2/ Phosphorus removal cost components requested were equipment, labor, energy, supplies and sludge handling and removal costs. The estimates obtained did not specify costs by line item.

3/ Actual effluent is higher ranging from 2.0 to 4.0 mg/l because the system is not operating, correctly. Research is being done to determine the problem. The cost for reaching the 1.0 mg/l design was estimated by the plant manager.

Exhibit B-11. Kent, Ohio Case

POTW Size Daily:	3.0 MGD
Annual:	1,095 MG
Secondary POTW Treatment Technology:	Activated Sludge
Advanced Secondary Phosphorus Removal Technology:	Chemical addition (alum)
Capital Cost Total:	$8,400,000 ($1985)
Phosphorus:	$30,000 ($1985)
Annual Operation and Maintenance Total:	$1,000,000 ($1985)
Phosphorus: 1/	$91,365 ($1985)
Phosphorus Influent:	7.0 mg/l
Effluent:	.5 mg/l - .6 mg/l
Removal Efficiency:	91 to 93 percent

Annual Cost Calculations:

Capital Recovery Factor at 20 years and 10 percent interest =	.1175
Capital Cost Phosphorus X CRF =	Annual Capital Cost
$30,000 x .1175 =	$3,525
Annual Capital Cost + Annual Operation and Maintenance Cost.=	Annual Treatment Cost
$3,525 + $91,365 =	$94,890

Phosphorus Removal Calculations:

Influent - Effluent =	Load Removed'
7.0 mg/l - .5 mg/l =	6.5 mg/l
7.0 mg/l - .6 mg/l =	6.4 mg/l
6.5 mg/l X 8.34 X 3.0 MGD X 365 =	59,360 lbs/yr
6.4 mg/l X 8.34 X 3.0 MGD X 365 =	58,447 lbs/yr

Cost-Effectiveness Calculations:

$\frac{\$94,890/yr}{59,360\ lbs/yr}$ =	$1.60/lb
$\frac{\$94,896/yr}{58,447\ lbs/yr}$ =	$1.62/lb

1/ Phosphorus removal cost components requested were equipment, labor, energy, supplies and sludge handling and removal costs. The estimates obtained only specified chemical, pumping, labor and sludge handling costs by line item.